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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

Vol. CX.

EDITED BY

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CORRIGENDA.

Vol. cix. p. 373, line 11 from the bottom, *for* "cylinder-stays" *read* "girder-stays."
„ „ line 10 from the bottom, *for* "cylinder" *read* "girder."

THE
INSTITUTION
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SESSION 1891-92.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

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26 April, 1892.
GEORGE BERKLEY, President,
in the Chair.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA.

(*Paper No. 2594.*)

"Electrical Measuring Instruments."

By JAMES SWINBURNE.

As the electrical industry develops, the methods employed in all its branches depart more and more from those in use in scientific laboratories. The vast strides made during the last ten years in the commercial use of electrical energy, are marked by departures from the practice of the experimental physicist, and approach to that of the mechanical engineer. In short, electrical engineering is daily becoming an important branch of civil engineering; and this has brought about a complete change in the methods of measurement. There are now workshop, as opposed to laboratory, instruments. It must not for a moment be supposed, however, that they are therefore necessarily less accurate. If one or two voltmeters were made in the year to supply the wants of a few laboratories, they would be bad and expensive; but when such instruments are turned out by the thousand, it is possible to devote much time and trouble to the design, and to make instruments at a low price which are accurate in use; just as the modern, low-priced American watch can be made better than its hand-made predecessors. Accuracy and low price are not, however, the only important considerations. Commercial instruments must be easy to use—that is to say, they must be direct-reading, or nearly so; they must not demand temperature-corrections or other calculations, and they must not be affected by local magnetic fields. These various instruments form the subject of this Paper. It is, however, unnecessary to discuss measurements that are the same in the workshop as in the laboratory, as descriptions, for instance, of methods of taking resistances with an ordinary Wheatstone bridge are given in every electrical text book. In such cases it will therefore be advisable to describe only those methods or instruments which are specially needed in commercial work, such, for example, as the determination of very large conductivities or very high electrical resistances. The exact measurement of resistances has been very thoroughly developed by telegraph engineers, and full information on this subject can best be obtained from the various telegraph manuals.

VOLTMETERS AND AMPEREMETERS FOR CONTINUOUS CURRENTS.

These two classes of instruments may be best discussed together, because in very many cases they differ in the windings only—that is to say, nearly all continuous-current voltmeters measure a small current which is proportional to the pressure on their terminals. There is one point of difference to which more attention is now being paid, and that is, that for use in central stations and in private installations, a voltmeter should be arranged to give clear and accurate readings through a small range. For instance, a station supplying at 100 volts does not require its voltmeters to read from 10 to 150 volts, but should be provided with instruments whose whole scale is devoted to readings between, say, 97 and 103 volts, if there are no feeders. The amperemeters, on the other hand, may be used for any currents up to their maximum. Stress is laid on these points because they are not generally realised either by instrument-makers or purchasers. For years designers have been devoting unlimited ingenuity to making instruments with equally-divided scales. An equally-divided scale is of no value, and, to secure approximately proportional readings, other important considerations in the design may have to be sacrificed. In addition to giving the readings required, all instruments should be direct-reading—that is to say, the index should point to the pressure or current, and there should be no turning of buttons on the top, or of reference to tables. Instruments whose indexes have to be brought to zero, such as the well-known Siemens dynamometer, have been of enormous value in the past, and have not yet been quite replaced in alternate-current work; but though indirect-reading instruments have still to be used, in many cases they should be avoided in central-station work. All instruments should have bold and visible scales, the dials being vertical, so that it is not necessary to go up close to the switch board to take a reading.

Nearly all makers are now adopting the clock form. It is generally more troublesome to make instruments in this way, because the forces dealt with are so small that it is difficult to make the pivots free enough to give accurate readings. Instruments with horizontal dials can have suspended moving systems, but the advantage to the maker is generally more than counterbalanced by the disadvantage to the user. In addition to these requirements, instruments must not have their readings affected by changes of temperature, produced by the electric power wasted in the coils, or by change of temperature of the room in which they are placed, and they must not be affected by external magnetic fields, which are always strong and variable in direction in electric stations. For use at sea, there is another requirement still—that the movements of the vessel should not affect the readings. It is most important that station instruments should be always in circuit without using much power. If station power is taken at 2*d.* per unit, every watt lost in the instrument is equal to the interest on £1 at 7 per cent. Exacting as these requirements are, they have all, or nearly all, been already filled by the various leading instrument-makers.

Of the many varieties of voltmeter and amperemeter that have been designed, only a few have survived; and, curiously enough, the most successful form is one that was at first regarded with the most suspicion. The majority of these instruments are now made with soft iron cores acted upon by coils in various ways. Such instruments were considered unpromising because they cannot be made to give proportionate scales except by empirical means, and because magnetic hysteresis gives rise to errors. It is now generally realised that proportional scales are not important; and the errors due to hysteresis have been reduced by careful designers till they are no longer perceptible. To avoid these errors, all that is necessary is to arrange the soft iron parts of the instrument so that only a small portion of the excitation due to the coil is spent on the iron. This means either that the induction in the iron must be very low, in which case the forces dealt with are small, or that the excitation due to the coil must be large, in which case there is waste of power and heating. High induction thus cannot be produced with few ampere turns, as the magnetic circuit must be chiefly through air. If it were chiefly through iron, the hysteresis errors would be considerable.

It would be of little use to illustrate the outsides of instruments, so diagrams are given which show the arrangements of the moving systems. The force acting on the moving system may be opposed by gravity or by springs. Most engineers have more confidence in gravity instruments; at the same time, springs are often very convenient, and must be employed for marine use. Their permanence has been frequently questioned; but, according to Kohlrausch, a good spring is absolutely trustworthy. Some springs creep, or take permanent or temporary sets, which may give rise to errors; but with care in selecting the material and in tempering, there should be no appreciable inaccuracy.

Fig. 1 shows the simplest form of soft-iron instrument. A soft-iron needle *a* is mounted on a pivoted arbor *b* inside a coil *c*, so that the field produced in the coil tends to turn it parallel with the direction of the induction. The movement is resisted by a small weight. This form of instrument was brought out some time ago by Miller, and different forms of it are made by Messrs. Crompton and Statter.

Fig. 1.

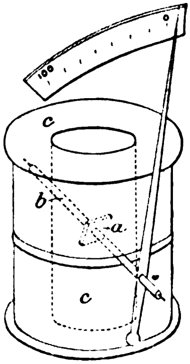


Fig. 2.

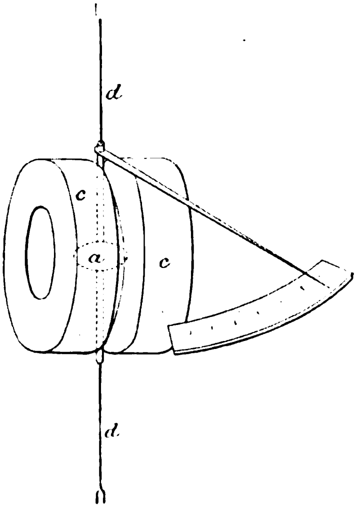


Fig. 2 is on the same principle, but the needle *a* is mounted on a vertical axis instead of a horizontal, and is held by top and bottom suspension wires, which also act as controlling springs. This is Lord Kelvin's marine voltmeter.

Fig. 3 shows an arrangement for giving a larger deflection in this form of instrument. The forms shown in *Figs. 1* and *2* have a maximum deflection of less than a right-angle; but that in *Fig. 3* has a maximum deflection of nearly two right-angles, as the arbor must turn through two right-angles, to move the needle from the position shown dotted to that shown hard.

Fig. 4 is a modification of *Fig. 1*. In this, the field is made stronger by providing the coil *c* with an iron core *e*. A large range is secured by bringing the needle *a* back to a normal position by means of a spring and milled head. The increased range is, of course, obtained at the expense of direct-reading. This is known as the Cunynghame voltmeter and amperemeter.

Fig. 3.

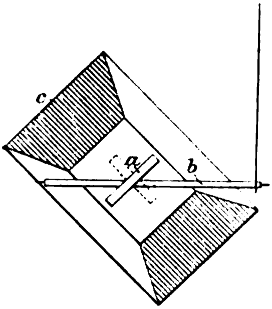
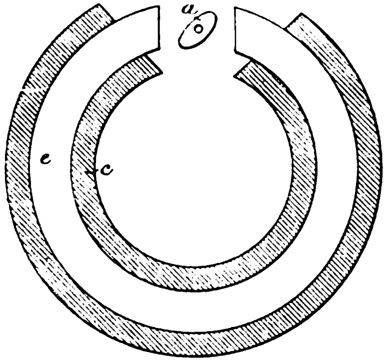


Fig. 4.



In the next form of instrument, the field due to the coil is modified by the presence of a fixed core or cores; and the soft-iron needle is arranged so as to tend to move from a weak into a strong field, the movement being opposed by weights or springs as before.

Fig. 5.

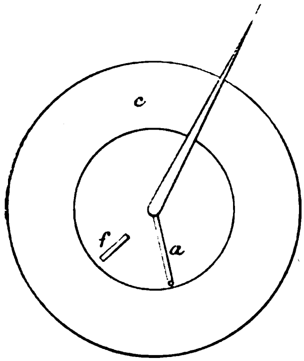


Fig. 6.

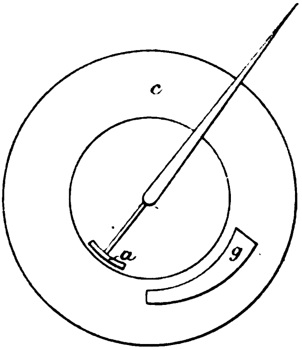


Fig. 5 is a diagram of the Edelmann voltmeter and amperemeter.

A small strip of soft iron *f* is fixed in the coil, and the movable piece *a* moves away from the weak field in its neighbourhood.

Fig. 6 is the Walsall instrument. Pieces of thin sheet-iron *g*, of a peculiar shape, are attached to the outsides of the coil to modify the field.

Fig. 7.

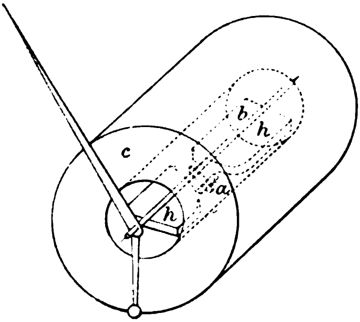


Fig. 8.

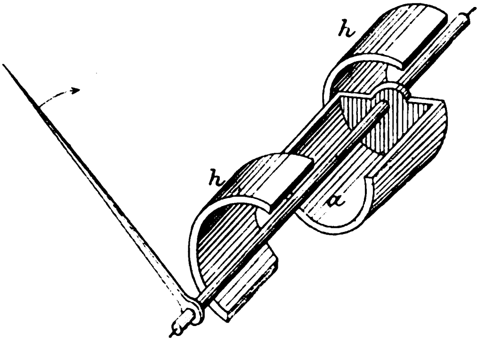
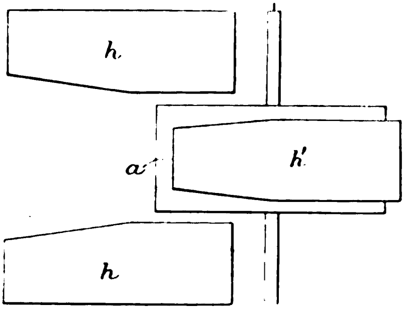


Fig. 7 is the core of an Evershed instrument. The field is modified by two short bars *h* placed inside the coil. The needle moves between them, and the ends are cut so as to make the field stronger at one side than at the other.

Fig. 8 is the core of one form of the Hartmann-and-Braun instrument; *h h* are fixed slips of sheet-iron, and *a* is a moving piece which turns to get into line with them. There is a third fixed piece *h′* outside *a* to repel it. This is omitted for clearness, but is shown in *Fig. 9*, which is a developed view of the parts.

Fig. 9.



Figs. 10 and *11* is another form, with *h* and *h* omitted.

The forms shown in *Figs. 5* to *11*, have an important advantage over those in which the needle turns on a centre. They are not so easily affected by external fields, because the north and south poles of the needle move in the same direction. The needle, therefore, cannot set itself in the direction of any external field, as the direction of the needle remains the same throughout the readings.

Fig. 10.

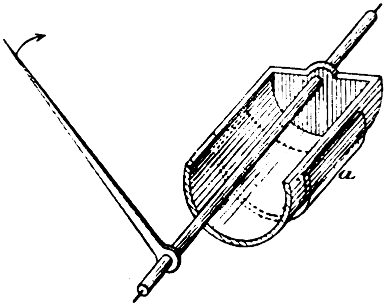
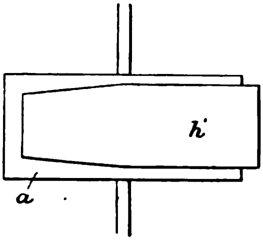


Fig. 11.



Figs. 12, 13, 14, show solenoids *c*, attracting soft iron cores into them. The movement is resisted by gravity in *Fig. 12*, which represents two instruments by Lord Kelvin and Dolivo Dobrowolsky. In Kohlrausch's instrument, *Fig. 13*, the movement is opposed by a spiral spring *i*.

Fig. 12.

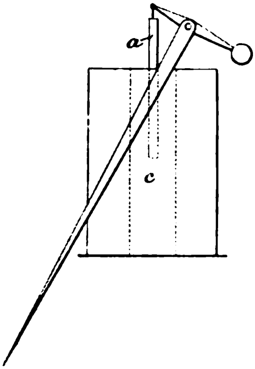


Fig. 13.

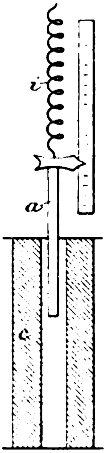
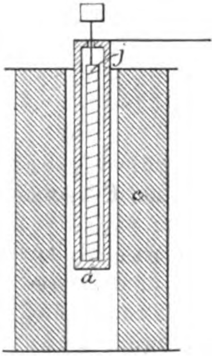


Fig. 14.



The instrument of Professors Ayrton and Perry, *Fig. 14*, is remarkable. The movement of the hollow iron core *a* into the coil *c* is opposed by a spring as in the last case, but it is in the form of an Ayrton and Perry twisted strip *j*. The core thus turns as it descends, and the index is attached to it, so that a small vertical movement of the core produces a large angular movement of the pointer.

Fig. 15 is a particularly ingenious arrangement, due to Messrs. Crompton and Kapp in England, and Professor Elihu Thomson in America. The needle *a* is either soft iron or magnetised steel, and it is free to move and take up any position. It is placed in a compound field, one component of which is produced by a coil *k* with a soft iron core *l*, and the other by a coil with no core. The field due to the coil with the iron core is not proportional to the current in the coil, as it depends also on the permeability of the iron, and this alters with the induction. The field due to the coreless coil is proportional, however, so the ratio of the two fields alters, and is measured by the needle.

Fig. 15.

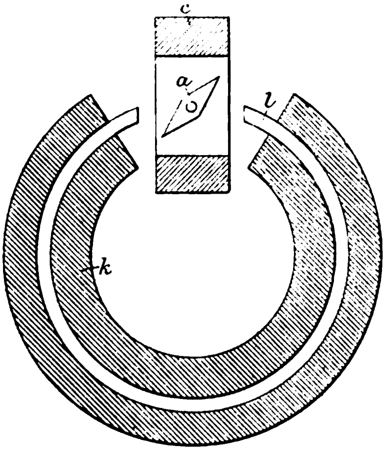
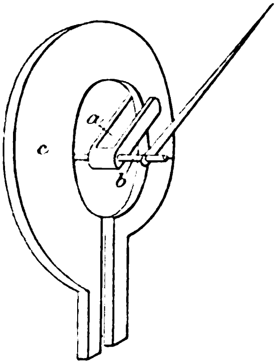


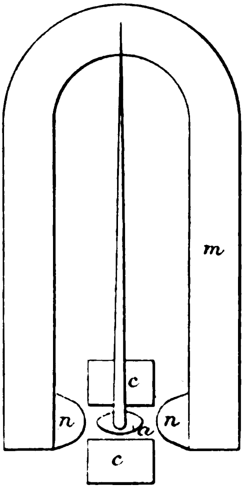
Fig. 16.



Instead of modifying the field in such instruments as *Fig. 5* by arranging fixed cores, the coil may be so arranged that the needle can move from a weak into a strong field. For instance, the arbor might be mounted eccentrically. A much better result is obtained, however, by Professor Elihu Thomson, in the instrument shown in *Fig. 16*. It is an amperemeter with only one turn of conductor *c*. The needle *a* is a sort of fork of soft iron, and it tends to move round to the narrow part of the conductor, where the field is stronger.

The next group depend on permanent magnets. The simplest form is an ordinary galvanometer with a permanent controlling magnet. Many instruments on the principle of the ordinary galvanometer have been made, but they all have the drawback of being easily affected by external fields. Messrs. Carpentier in France, and Professors Ayrton and Perry in England, sought to overcome this difficulty by using very strong controlling fields. Unfortunately, they went too far, and made the field so strong, and left so little room for the deflecting coil, that it was apt to become hot. This form of instrument is still made in large quantities, especially in France. It is shown in *Fig. 17*, where *a* is the needle, and *m* the permanent controlling magnet, with polepieces *nn*; *c c* are the two deflecting coils.

Fig. 17.



Almost the only survivor of the tangent galvanometer instrument, is Lord Kelvin's lamp-counter.

The soft iron needle of such an instrument as the Miller, *Fig. 1*, may be replaced by a hard steel magnetic needle. This form is generally used as an amperemeter, the coil being replaced by a single bar, against which the needle is mounted. It then tends to set itself at right angles to the bar, the tendency being opposed by gravity or springs, as the case may be. This form is made by Messrs. Paterson and Cooper, and Messrs. Latimer Clark, Muirhead and Company. Messrs. Siemens and Company make another form of the same instrument, in which the needle is suspended in the field due to a double coil. The force is balanced by turning a milled head, until the needle is brought back to the original position. Such an instrument is not direct reading, but has a large range, and does not need a dial specially engraved after calibrating. It is, however, easily affected by external fields.

The moving coil, or, as it is sometimes called, the Deprez D'Arsonval galvanometer, can be used as a voltmeter either in its laboratory form, in which case it is hardly an engineering instrument, or arranged for commercial use. Mr. Weston's form is shown in *Fig. 18.* A strong permanent magnet *m*, embraces a coil of fine wire, *o*. Inside this there is a fixed soft iron core, *p*. Any current in the coil tends to turn it like the coil of a dynamo armature; this force is opposed by two hair-springs *qq*, which also serve to lead the electricity in and out. The moving-coil form of instrument has many advantages. It is not affected by external fields, and it is very sensitive, so that it can be made of high resistance, and can be left permanently in circuit without heating, or introducing temperature errors. Messrs. Carpentier have also introduced a form with wire suspensions instead of pivots, and with the magnetic field arranged so as to give readings through a large angle.

Fig. 18.

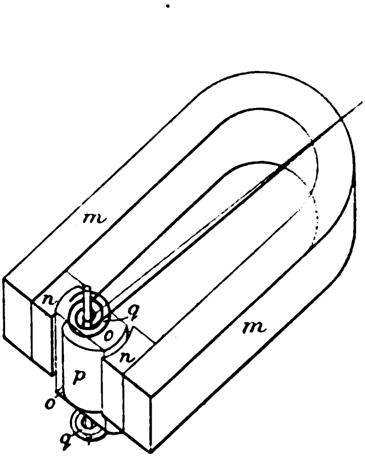
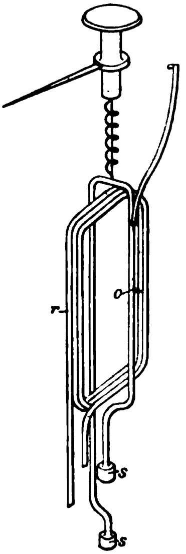


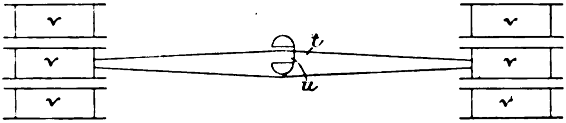
Fig. 19.



The Weber dynamometer still survives in the Siemens dynamometer, and in Lord Kelvin's balances. The Siemens dynamometer, *Fig. 19*, consists of a fixed and a moving coil, *r* and *o*, suspended at right angles. The moving coil tends to arrange itself parallel to the fixed coil, and the force is resisted by a spring *q*, and milled head. The contacts to the moving coil are made by mercury cups, *s s*. This instrument is not direct-reading, and is influenced by external fields, but is still largely used in alternate-current work.

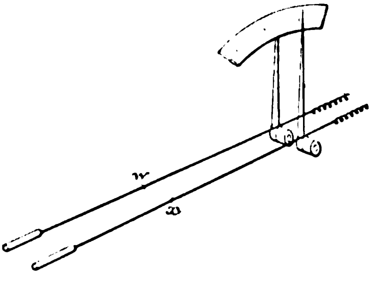
The Kelvin balances are really carefully made scales, for weighing the force exerted by coils carrying currents. The principle is shown in *Fig. 20.* The great difficulty in such instruments, especially for use as amperemeters, is to make the connections without interfering with the accuracy of the balance. Lord Kelvin has overcome this, by suspending the moving system by a number of fine wires. These can carry large currents, and are much more flexible than a single thin strip. These instruments are not direct-reading, but that is a small matter, as they are intended not as station or installation instruments, but as secondary standards for those who have no standard cell gear. Some forms are, however, made direct-reading, for engine-room use. The beam *t* is supported by the ligament *u*, made up of fine wires; *v v* are the coils.

Fig. 20.



The next form depends on the heating of a wire by the current in it. *Fig. 21* shows the first practical form of this instrument, due to Mr. G. M. Hopkin. Two wires *w x* of the same material are used. The expansion of one, *x*, moves an index, and this wire carries the current. The other, *w*, is arranged so that its expansion moves the dial. This is necessary, as, without compensation, the reading would depend partly on the temperature of the air where the instrument happened to be. In the form shown, the reading depends on the difference of the temperatures of the two

Fig. 21.



wires, not on the absolute temperature of one of them. By far the best known and most used of the hot-wire instruments, is that of Major Cardew. In this, all the details have been worked out with the greatest care, and a thoroughly commercial instrument has been produced. The wire *x* is made so long that the instrument can be used for 150 volts, and the readings are increased by multiplying gear *y*. The arrangement is shown in *Fig. 22.* Compensation should be made for change of temperature due to the heating of the instrument by the current, and for change of resistance due to external variations of temperature. The first correction is made in some instruments, by making the case which holds the wires of brass and iron tubes so proportioned as to have the right expansion, and the second is omitted. It is said that the reduction of the viscosity of the air at the higher temperature compensates for the increase of resistance due to the instruments being placed, for instance, in a stoke-hole. In other instruments, the index is brought back to zero by a small screw, to eliminate the error due to the rise of temperature by internal heating.

Fig. 22.

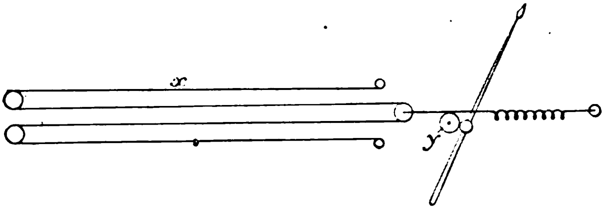
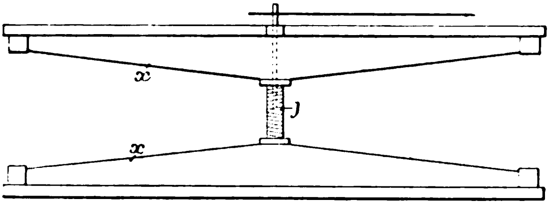


Fig. 23.

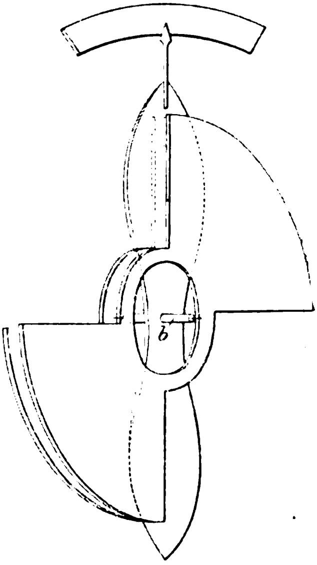


Professors Ayrton and Perry have brought out a hot-wire instrument, in which the expansion of the wires *x* allows them to sag, and the sag is measured by one of their strip springs *j*. This ingenious instrument is shown in *Fig. 23.* The wires may be coupled in series so as to be used for 100 volts, or in parallel for testing batteries, and such work. It is difficult to compensate this form of instrument for temperature errors. If the body is made of metal or alloy with the same temperature coefficient as the wire, the expansion error can be corrected; but the resistance error still remains, as in the Cardew, and, of course, the body of the instrument takes some time to heat.

Messrs. Hartmann and Braun make a hot-wire instrument, in which the sag of the wires allows the spring to turn the index. This form can be compensated for temperature in the same way as the Cardew.

The next form of instrument involves the use of a standard cell. A standard cell is sometimes used, in conjunction with a reflecting galvanometer and a set of resistances, or even a stretched wire, for measuring both pressures and currents. This arrangement can hardly be considered applicable to commercial use. Mr. Edison has, however, made voltmeters which contain the necessary resistances and standard cell inside the case. They are not direct-reading, as the resistance has to be adjusted till the needle comes to zero. Such voltmeters may be made very accurate, but there is some uncertainty as to the trustworthiness of standard cells subjected to such continuous rough usage.

Fig. 24.



Voltmeters are also made which depend on electrostatic action. *Fig. 24* represents Lord Kelvin's electrostatic voltmeter for high pressures. It is practically a quadrant electrometer, with a horizontal arbor resting on knife-edges, and a gravity control. This form is not sensitive enough for such pressures as 100 volts, so Lord Kelvin has designed another form with a wire suspension. In this electrometer, instead of one quadrant, there are several, so that enough torque is obtained to twist the suspending wire. If a single cell were used, the suspending wire would have to be very fine or very long, and this would make the instrument unpractical. The use of several cells admits of a suspension of reasonable thickness. This instrument has a horizontal dial, but it is provided with a mirror, so that the readings are visible in front, if it is on the level of the eyes.

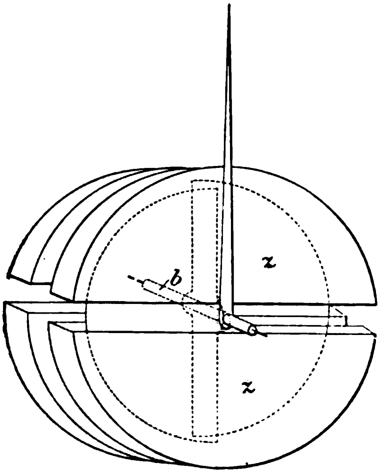
Fig. 25 shows the Author's station voltmeter. Instead of quadrants, it has half-circles, two pair being used for symmetry. A gravity control is employed, and the moving system is so shaped that the index traverses the whole scale between, say, 1,800 and 2,200 volts. This instrument is useless for low pressures.

In describing these instruments continuous currents have been alone considered; and it will be best to discuss alternate currents by themselves.

ALTERNATE-CURRENT VOLTMETERS AND AMPEREMETERS.

Many instruments already described will do equally well for continuous and alternate currents. This is the case more especially with amperemeters. Of course all instruments with permanent magnets are out of the question for alternate-current work. A soft iron amperemeter which is so arranged that the iron does not produce hysteresis errors with continuous, will generally work with alternate currents, if the iron is laminated so as to avoid Foucault currents. In order that such an instrument shall work correctly, it is necessary that the force at every part of the period should be proportional to the square of the current. If the induction is strictly proportional to the current the reading is thus correct. If the induction is appreciably affected by hysteresis there is an error. If there are any Foucault currents in the iron core, or in the brass work of the instrument, the iron is not fully magnetized, and the reading is too low.

Fig. 25.



In order that a voltmeter should be available for alternate currents it must be made with no appreciable time-constant, else it reads too low. It can, of course, be calibrated for a particular frequency; but that is not of much use, as stations do not keep accurately enough to stated speeds. Various methods have been proposed for overcoming this difficulty. The simplest is to use an instrument on the Weber dynamometer principle, either wound with wire of a very high specific resistance, or arranged with a non-inductive resistance in series with it. This arrangement involves too great waste of power, and most electro-dynamometers are not direct reading. Mr. Gray has proposed to arrange Lord Kelvin's balances so that the two coils repel each other. The mutual induction of the two parts of the circuit then largely compensates for the self-induction of the two coils in series. Mr. Evershed and the Author have proposed to compensate for self-induction by means of condensers, and by other methods involving small choking coils. The condenser method reduces the error, but there is still a small variation if the frequency varies. Lord Kelvin has recently introduced an electrometer made sensitive enough to read down to 60 volts. This instrument, which has been already noticed, is most convenient, as it takes no power, is not affected by external fields, and has no temperature errors. Its only drawback is its horizontal dial. By far the most generally used alternate-current voltmeter is the Cardew. It acts just as well with alternate as with continuous currents. Most alternate stations run at 1,000 or 2,000 volts. The electrostatic form of instrument is therefore much the best, as it is easily made, and takes no power. Such instruments will of course work equally well with alternating or continuous currents.

One of the most complicated questions in connection with alternate currents is the measurement of power. The ordinary wattmeter as used in continuous-current work consists of a fixed and movable coil. One is of thick wire and is in series with the current, and the other is in shunt and takes a current proportional to the pressure. The force acting on the moving coil is then proportional to the product of the pressure and current, that is to say, to the power. This instrument is exceedingly useful in incandescent-lamp testing, but it demands a correction. If the pressure coil is put in shunt to the lamp only, the current coil takes the current of the lamp and the current of the pressure coil, so that the reading is too high. If the pressure coil is arranged in shunt to the lamp and current coil it has the extra pressure due to the drop over the resistance of the current coil, so that the reading is again too large. In fact the wattmeter really reads the power spent in the circuit to be measured plus that spent in one of its own coils. This error can be compensated so as to make the instrument read correctly, but this compensation is necessary only when small powers are to be read. Reference for particulars may be made elsewhere.[1] In measuring alternate powers another error comes in, due to the time-constant of the fine wire or pressure coil. This reduces the current in the pressure coil, so that the reading on non-inductive circuits is too low, and also makes it lag, so that the instrument reads high on inductive circuits. Though an ordinary wattmeter, as used for continuous current, is not suitable for alternate work, there is no real difficulty in making an instrument which is sensibly correct with alternate currents. The current coil should produce a strong field, and the pressure circuit should have comparatively few turns on the moving coil, a non-inductive resistance being arranged in series with it. There is an undeserved prejudice against the dynamometer wattmeter. On the other hand, the same instrument, arranged so as to have greater errors and called a split dynamometer, has till lately been treated as accurate. Several methods of measuring power by electrostatic instruments have been proposed. The electrostatic analogy of a dynamometer wattmeter cannot be found, for the mutual attraction or repulsion of two electrified bodies is as the square of the difference of potential, while in the dynamometer the force is as the product of the currents in the coil. All methods of measuring alternate power electrically involve non-inductive resistance, and therefore they all have the same error from such resistances not being accurately non-inductive.

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[1] Report of the British Association, 1887.

There is no difficulty in making a resistance which has no sensible time-constant. The Author's form of wattmeter has a moving system, consisting of a few turns of wire, with a non-inductive resistance in series, and this form of instrument is accurate within the limits of observation. Put on an inductive circuit with 100 volts and 5 amperes, which was known to have a loss of about 12 watts, the instrument read within 2 watts of the calculated power. On a condenser taking 2,000 volts and 3 amperes, or an apparent power of 6,000 watts, it gave no deflection. If a little care is taken in designing, so that there is no appreciable self-induction, and if a little trouble is taken in manufacturing, so that there is no leakage across the resistance even under pressures of several thousand volts, alternate-current power can be measured as easily and as accurately as in the case of continuous currents.

Though the dynamometer wattmeter is the only instrument that can be discussed in a Paper devoted to commercial measurement, mention may be made of the various other methods proposed. The application of the electrometer is due to Professors Ayrton and Fitzgerald. Two readings are necessary. The errors in this method are likely to be large, because the power is the difference of two comparatively large values determined by the two readings, so that a small percentage error in the readings means a large percentage error in the power. In order to reduce this error, a large shunt resistance must be used, and this at once makes the method unpractical. For instance, if the power going into a transformer taking 2,000 volts and 10 amperes is to be taken, a resistance that also takes 2,000 volts in series with it wastes some 27 HP., and demands a dynamo giving from 2,800 to 4,000 volts. Messrs. Blondlot and Curie and the Author have made forms of direct-reading electrostatic wattmeters which overcome this difficulty. They give accurate readings with comparatively small resistances in shunt. They are, however, not so convenient to use as dynamometer wattmeters. Messrs. Sumpner and Ayrton and the Author independently published a method involving three voltmeters. The three instruments do the work of the single direct-reading electrometer wattmeter, so this method is of purely scientific interest. The power is found by subtracting the sum of two readings from the third reading, so that if this difference is small in comparison with the readings, large percentage errors may creep into power determination. Large resistances are therefore again necessary, and the method is of little practical use. Dr. Fleming has much improved the triple-instrument method by working with currents instead of pressures. By this means he avoids the necessity of, for instance, having to use 4,000 volts in testing a 2,000 volt transformer; and he makes it possible to use the three-instrument method in central stations. It is, however, useless to employ complicated methods of measuring power when a simple one is better. The prejudice against the ordinary wattmeter has no real foundation. It is easy to make calculations involving R and L, and to work out the errors due to L, thus making out that the wattmeter is not accurate. But if any one will take a real instrument, designed with a little care, and substitute the approximate values of R and L, he will find that he has been straining at a gnat. In addition, it must be remembered that all the other methods mentioned have errors due to L, and frequently others in addition.

RESISTANCE.

Electric-light engineers seldom have to measure moderate resistances, and resistance measurements are always described in text-books. It may not be out of place, however, to comment on the absence of resistance-boxes meeting electric-light requirements. The comparison of electrical forces can be made with greater accuracy than any other kind of measurement. A good chemical balance will weigh within one in a hundred thousand, but electric pressures, currents or resistances, can be compared within one in a million. Electrical measurement is less accurate than weighing, solely because of the difficulty of preparing constant standards. Resistance-boxes can be made with great accuracy, and can also be easily checked; the result is that an engineer who is quite satisfied with a voltmeter which may be 1 or 2 per cent. wrong, insists on having a bridge which is accurate within one in ten thousand or a hundred thousand, costing well on to £30. Apart from the excessive cost of such apparatus, it is not suitable for practical work. Plugs are the best means of making good contacts, if they are well made and are kept thoroughly clean. The plugs of most resistance-boxes are not well enough made, and are not kept clean. Resistance-boxes for commercial work should therefore be made with switches. A switch can be made to give a very good contact; but even if it did not a switch-box still comes out better than most plug-boxes. Take an extreme case. Suppose a post-office bridge with twelve plugs in the adjustable part, each with a constant resistance of, say, 0·01 ohm, the total contact resistance varies from 0 to 0·12 ohm. A switch-box to give the same range has four switch contacts. Suppose the resistance of each to be 0·02, the total contact resistance is 0·08, but this is always in circuit. The errors are due, not to the resistance of the contact, but to their variations, that is to say, the error is of a higher order. The box can be arranged so that the resistance of the connections and contacts are all allowed for in the one ohm coil; this cannot be done in the ordinary arrangement, so that the switch system is very much more accurate. In addition to this it is very much more rapid in use. With a dead-beat galvanometer and a switch resistance-box, a resistance can be taken in a few seconds instead of some minutes. The ordinary resistance-box is made of the post-office pattern to suit telegraph and not electric-light requirements. Instrument-makers should therefore turn their attention to apparatus for measuring very high and very low resistances. For low resistances it is necessary that the contacts should not be in the circuit to be measured, so that some feeler arrangements like those due to Mr. Heaviside or Lord Kelvin are necessary.

More progress has been made in measuring small conductivities, such as those of the wiring of installations. One method is to use a battery of some thirty cells, to take a reading with a galvanometer in series with, first, a standard resistance, and second, the wiring to be tested. From these readings the insulation resistance is obtained. The chief drawback to this arrangement is the weight of the apparatus. There is great need of some cell which can give a volt or so, and does not weigh more than perhaps a fraction of an ounce. The current needed from such cells is, of course, exceedingly small, a-tenth of a milliampere for instance, and there is no reason why they should not be very minute.

Some years ago Lord Kelvin brought the ohmmeter before this Institution. It consists of a magnetic needle which is free to turn. This is acted on by two fields; one is due to a pressure, and the other to a current coil. The needle takes up a position depending on the direction of the component of these fields, so that it indicates the ratio, and the instrument can thus be graduated in ohms. Mr. Evershed has brought out an ingenious apparatus consisting of an ohmmeter and a tiny dynamo. The little dynamo develops the pressure, thus avoiding the necessity for cells, and the ohmmeter measures the resistance. This apparatus is used for testing insulation. Messrs. Hartmann and Braun have also brought out several forms of insulation testing apparatus. Some of these also have small machines; but in one case a bell is rung through different resistances, and in another an amperemeter is put in series. This may at first seem rough, as the speed of turning may alter. But if the operator always tries to turn it 60 revolutions per minute the speed will not vary more than 10 or 15 per cent., whereas the insulation resistance of a given installation frequently varies 100 per cent. from day to day owing to minute leaks over damp surfaces. For ordinary work such an arrangement is therefore accurate enough.

METERS.

By far the most important instrument of all is the meter. The pressure and current indicators in a station cost little in comparison with the heavy plant; but the question of meters is most serious because one must be provided for each customer, so that they are very numerous. The requirements are that the meter should be accurate throughout its load. For years Supply Companies, especially those using alternating currents, have been obliged to content themselves with meters in whose favour all that can be said is that they go faster if the load increases. The enormous difference in the revenue due to inaccurate meters does not seem to be fully realised. A meter that reads 2 or 3 per cent. wrong, may make all the difference between working at a loss or at a profit. It may be urged that inaccuracy does not matter, because it tends to average about right. This is, however, very doubtful. The inspector is not likely to pass meters that read much too high at any parts of their range; and most give too small readings at light loads. It is most advisable that meters should start with a single lamp, out of at least 100. Very few motor meters come near this. Suppose a house is wired for 100 lamps, and its average load is equal to 10 lamps always on; and suppose one lamp is burning all day in a dark passage, but is not counted by the meter. The error is 10 per cent. against the Supply Company. If the Company were to replace the meters by some accurate form they would increase the revenue 10 per cent. with no extra expenditure, which is enough to turn a failure into a brilliant success. Errors due to temperature variations may frequently be 10 per cent. or more if copper is used. As a matter of fact copper is often used in some forms of meter, owing to the high resistance of alloys with low temperature coefficients. Meters which are correct when adjusted at the same temperature, may vary very largely if one is placed in a cold cellar and the other in a warm front hall, or in a kitchen.

It is most important that the meter should not itself waste power. If the cost of extra energy is taken at only 2*d.* per kilowatt hour, every watt lost in the shunt circuit of a motor meter costs 1*s.* 6*d.* per annum. Taking interest and depreciation together as high as 7 per cent., this means £1. That is to say, the price of the meter must be considered as increased by £1 for every watt taken in the shunt circuit; so that a £15 meter which has no continuous waste is to be preferred to a £5 meter that takes more than ten watts continuously. The various sources of error can best be discussed in connection with particular forms of meter. It is questionable whether any parts of a meter should be allowed to go at high speeds. A motor meter with an armature running at 1,000 revolutions per minute will probably wear itself out soon, but it is difficult to say whether the speed should be limited to something like 100 or to about 10 per minute. The balance of a watch performs 300 reciprocations per minute for many years without perceptible wear. Other things being equal, of course low speeds are best. A meter should not cause a drop by setting up a perceptible back pressure, or by absorbing too much power in resistances. The loss of 1 per cent. means not only a waste of 1 per cent. of the energy paid for, but that the lamps will be run some 5 per cent. under candle-power, so that the consumer gets 5 per cent. too little light, and cannot run his lamps properly. A quarter, or, at the very most, half a volt in a 100-volt installation is all that should be allowed as full-load drop in the meter. A meter should be direct-reading; preferably it should have an index like that of a gas-meter. This is not a matter of real importance; it is a concession to prejudice. When gas came into use gas chandeliers were made, and it was pretended that candles were being burnt. Now that electric light has been introduced, the fittings are altered a little more, and it is pretended that gas is being used. The chief advantage of direct-reading is that it allows the consumer to see how much he is using, and this gives him confidence. It is still usual for makers to send out meters whose readings have to be multiplied by a constant. This slovenly practice will probably soon die out. It used to be common in the case of volt- and amperemeters, but is now discarded in instruments of the best types.

It is questionable whether mercury is admissible in a meter. Mercury appears to give trouble when used in connection with a commutator. The surface is apt to become oxidised, and the mercury separates into a number of minute globules. Many forms of meters have mercury whose surface is not changed, the moving part being wholly immersed. In this case the mercury is not likely to become "dead." The next trouble is amalgamation. Even the vapour of mercury will amalgamate. The train and all the mechanism must therefore be made of iron, steel or nickel. Nickelled brass will stand for some time, but electro-deposited nickel is so porous that it is questionable whether mercury will not eventually destroy any meter containing brass, tin, or copper. These statements as to the action of mercury are open to contradiction, and the results of experience extended over some years would be valuable.

All the parts of the meter should be strong, so that the mechanism is not likely to go wrong, All sorts of watchwork are to be discouraged. A meter containing any kind of delicate mechanism may work on the test-room table; but it is quite another thing when it is in practical use. At present, while electric light is, to some extent, a novelty, the housing of the meter receives some little extra attention; but it will soon share the fate of the gas-meter, and be put in any out-of-the-way cellar, where it will be exposed to dust and damp, and perhaps traces of corrosive gases. In addition to this, most meters are slightly warm, and this attracts all sorts of insects, which can usually find entrance if the cases are not very carefully closed. Many meters are stopped by insects; and it is foreseeing such contingencies and providing for them, that constitutes the principal difficulty in developing a new industry.

Above all, it is necessary that meters should be cheap. There is no difficulty in designing a beautiful meter which shall cost £20 or £40; but that is not the problem. What is required is a meter which is accurate enough for commercial use, and which costs as little as a gas-meter, or even less.

Electric meters may be divided into several classes, and these will be taken in order.

The chemical, or electrolysis, meter is largely used in America for direct current work. A low resistance is inserted in the main circuit, and a high resistance in shunt to it. In the high-resistance circuit a voltameter is inserted. Mr. Edison uses zinc in zinc sulphate for his voltameter, and appears to get very good results. If amalgamated zinc is used, an electromotive force of a millionth of a volt on the voltameter is enough to work such a meter; there should be no error if the zinc sulphate solution is used diluted so that it remains homogeneous, and if the plates are well amalgamated. This meter is not used in this country. It has only one drawback, and that is that the deposits have to be weighed. On the other hand, it has the advantage of cheapness in manufacture, and is not apt to get out of order. It is then a question whether the trouble of weighing is not more than paid for by the gain in first cost. If the meter costs £5 less than one with an index, the interest on the saved money taken at 7½ per cent. is 7*s.* 6*d.* a year. If the inspector calls once a quarter it will pay to use this form, if the weighing takes up less than about 2*s.* worth of his time. It is not at all likely his time would be so valuable as this. There is, however, a great prejudice against such meters.

For alternate currents aluminium may come into use. This is the only metal which cannot be deposited electrolytically, so that the quantity of electricity passed can be found from the loss of both plates. It is difficult, however, to obtain aluminium quite free from silicon and other impurities, and the plates are apt to dissolve slowly even when there is no current. Mr. Wright has used copper voltameters in series with high resistances as meters in series distribution. Such a meter really integrates the pressure, and, as the current is constant, the energy taken is readily found.

The largest class of meters depend on small motors. The motor is generally arranged to do work on a brake. The brake usually employed is an Arago disk, or some sort of fluid friction arrangement, such as a fan in air or in a liquid, as for example mercury. The meter may be coupled up in many ways; the armature and the field magnets may be in the main circuit, or may be in shunt circuits across the pressure terminals of the house and so on, or permanent magnets may be used for the field. Alternate-current meters again demand special motors. The meter may have a number of armature turns and a commutator, or it may be of the one turn type which demands no commutator. To make a meter accurate there must be a law underlying it. If a voltmeter does not give a straight line law, the scale is graduated to read correctly; it would be hopeless to take such a voltmeter as most of the soft iron instruments described, and to tamper with the shapes of the parts until a straight line law was obtained; and no one who had experience of instrument manufacture would have confidence in the result. In fact each of the instruments would have to be manipulated individually. In practical work, therefore, when accuracy is required, the scale is altered to fit the instrument. In a meter this cannot be done. It must be made to give a straight line law; or in other words, a meter must be based on laws in accordance with which it moves its train at a speed proportionate to the current or power as the case may be. It must not follow some other law and be manipulated till it gives readings which may be nearly right, but are probably still very wide of the truth.

Motor meters, with the field in series with the armature, work under disadvantage. The brake in this case is generally fluid friction. There is some doubt as to what law fluid friction follows. It is at times said that the force varies as the speed, and at others that it varies as the square of the speed. According to one theory the force varies as the speed as long as that is small. When the speed reaches a certain value vortices are produced, and the force varies as the square of the speed. A series meter is correct only when the torque varies as the square of the speed, and the power as the cube; at low readings it will be against the Supply Company. If the torque is the sum of two torques, one of which varies as the speed and the other as the square of the speed, the meter will work correctly if its field has shunt-and-series windings in the proper proportions. Some series meters are arranged with shunts, but the object is generally understood to be to overcome the difficulty of starting. In addition to the fluid friction, there are the frictions of the pivots, and of the film of oxide on the surface of the mercury, when that has to be overcome. A series meter has only one-ten-thousandth part of its full load torque available at 1 per cent. of the full load. The shunt series arrangement has a much greater torque. The whole question of fluid friction in meters demands investigation. Some fluid friction meters are series wound, some have constant and some compound fields. They cannot all be right. There is still another objection to series and compound fields for direct current work, and that is that errors arise through hysteresis. If the meter has been reading at full load, and the load is greatly reduced it will read too high. The Arago disk and all other arrangements involving Foucault currents take torques proportional to the speed, and power proportional to the square of the speed; not torque proportional to the square of the speed and power proportional to the cube, or to the speed. This point is of great importance in the theory of meters, more especially as it is frequently incorrectly stated. Even the French Commission, when they awarded the prize of F. 10,000, were inaccurate on this point. The difficulty of starting at small loads occurs in all meters following square laws. If, for instance, 100 amperes yield torque which affords a reasonable speed for the full load of the meter, then 1 ampere would give only one-ten-thousandth part of the torque, as just explained, and that is generally too small to start the meters. A shunt round the field can never be the right way of starting a meter. An extra armature-current is what is wanted, but that cannot well be arranged economically, at least in continuous-current meters. No residual torque arrangement can ever be accurate, however, because the starting friction is always much greater than the stopping friction. If the meter has a permanent torque which will just start it, it will never stop. If the permanent torque just allows it to stop, it will not start without an appreciable load.

Faure appears to have been the first to use a one-turn motor with mercury, but as his meter has not come into commercial use it is unnecessary to describe it.

Mr. Ferranti uses a series one-turn motor meter. This inventor has struggled for years against difficulties inherent in the series motor. To make it start, he excites the field partly by a shunt circuit arranged across the terminals of the installation; or, as it may be called, a pressure circuit. The brake is supplied by the friction of the mercury and mechanism. If the torque necessary to overcome this friction varies as the speed, the field should be shunt-wound entirely, not partially. Mr. Ferranti appears to have found this out by experiment, and his latest form of meter has a constant field. In the form with the shunt field, there is a temperature error due to the variation of the resistance of the shunt.

The Teague meter is on the same principle. In this case also a one-turn, or unipolar, motor, is employed. The armature has a disk with a radial current. The outside is turned down to run in mercury, and the inside runs in a central mercury cup. It is thus a disk with radial current and mercury connections. The field in this meter is also wound partly with a constant pressure shunt, and partly in series with the armature. The shunt, as in the case of the Ferranti meter, makes the torque more nearly right at very small loads; but the series winding, unless the brake torque increases faster than the speed, seems to be wrong.

Among constant field motors Mr. Ferranti's permanent magnet form has already been mentioned.

In the Hookham meter, the field is a permanent magnet. This arrangement is most important as it absorbs no power. The armature has several turns, and a commutator whose sections dip into mercury. The large meters are shunted by low resistance, so that a portion only of the main current is carried by the armature. This meter has no appreciable temperature error, as the low resistance shunt is platinoid, and the armature turns are wound on the Arago disk, so that it is at the same temperature, as well as of the same material, so that the effects of change of resistance cancel each other out. The mercury commutator contacts seem to be the only drawback to this type.

The Hartmann-and-Braun meter has a one-turn armature in the form of a disk, but the whole of the disk is not in the field, so that it acts both as armature and brake. The contacts are made by mercury cups, but the immersed parts are continuous. The field magnet is excited by a pressure current. This is, of course, a disadvantage, as it means a continuous waste of power.

The next form is due to Professor Perry. The moving system is a copper disk. This is submerged in mercury, so that the frictional resistance at the surface causes little trouble, as the rotating part is of small diameter where it emerges from the mercury. The movement of the armature is opposed by Foucault currents, but they are in the disk itself, not in a separate brake. The meter is the same in principle as the Hartmann-and-Braun, but the details are different. The field is notched so that if the armature is still, the current spreads uniformly, but if the disk can move, it rotates at such a speed that the current leaves those parts of the armature which are in the strong field, and flows where there are gaps. Similarly, in the Hartmann-and-Braun meter, if the armature is still, the current will flow chiefly between the poles; but, if the armature is free to rotate, it will go at such a speed that the current flows round so as to avoid the field. This is merely another aspect of the Foucault current explanation; but it is always advisable to look at things from as many points of view as possible. Professor Perry's meter has a very small armature, with little friction. It should therefore start with a small fraction of the full load, and should move very slowly at all times.

Though this meter has been taken in order, and has been described as a modification of the numerous motor meters, it must not be forgotten that, in a sense, Professors Ayrton and Perry have invented nearly all the types of motor meters now in use. Some nine years ago they laid down the principles involved in their construction with perfect clearness, and though motors had been previously described, it is questionable if any one until then clearly understood the matter.

The next form to be discussed is the joulemeter, or, as it is often inaccurately termed, the wattmeter. So far coulombmeters have alone been described. It has often been pointed out that a joulemeter is better because the consumer is supposed to be charged by the energy used, not by the quantity of electricity. On the other hand, it is urged that the pressure is kept constant, so that a coulombmeter is all that is needed. The pressure is seldom exactly as it ought to be, and the joulemeter is therefore really preferable from that point of view. To make charges really fair to the customer the meter should read according to the light given by the lamp, that is to say, it ought to run about 5 per cent. slow for every 1 per cent. the pressure is below the normal, as the light decreases in about that proportion; and should run very slow, or even perhaps backwards if the pressure is above the normal, as the Supply Company is then seriously reducing the life of the consumers' lamps. Such meters as these are, of course, impracticable; so, other things being equal, the joulemeter is best. A joulemeter, however, must have a high-pressure circuit in which power is being wasted continuously, and it is then a question whether it is not better to use a coulombmeter, which sometimes means a loss to the one party and a gain to the other, than to have an accurate meter which involves a dead loss. Take, as a sample case, a house with fifty 30-watt lamps, the full load is 1,500 watts, the average load, say 125 watts. If the Company runs the circuit at 101 volts instead of 100, and charges by a coulombmeter at 8*d.* per Board-of-Trade unit, the price is 2*s.* per day. If the joulemeter is substituted the charge is increased 1 per cent. If the joulemeter itself absorbs 10 watts, the cost of this, taking extra power at 2*d.* per unit, is 0·48 per day, so that the customer has to pay more, and the company loses too. It is possible that 10 watts is an outside estimate, and it is also possible that a small cut-out, which opens the pressure circuit when no lamps are in use, may be employed.

In the Thomson-Houston meter, invented by Professor Elihu Thomson, the armature is retarded by an Arago brake, which is of large diameter and has three magnets, so that it is strong. The field magnets of the motor are two stationary coils which have no iron core, and the armature is made up of coils of fine wire which form the pressure circuit. The resistance of the small commutator does not interfere with the accuracy of the instrument, as it is in series with some thousands of ohms. The meter seems to be almost perfect, but has some drawbacks. It is a question whether the omission of iron in the field does not involve too great a loss in the fine wire circuit or excessive drop in the series coils. To reduce this is only a question of workmanship. The same form of meter is available for continuous or alternating currents, which is a great advantage, and tends to cheapness of manufacture.

The Hummel meter is the same as the Thomson in principle. The Foucault currents are produced by an electro-magnet, however, which converts it from a joulemeter into a coulombmeter. It is also possible to get much greater damping by means of an electro-magnet, so a lower speed may be employed. As has been already mentioned, it is an open question whether it is best to measure the energy or the quantity; but by coupling the electro-magnet in series with the armature, Mr. Hummel makes it difficult to compensate for temperature. For instance, suppose the temperature to rise enough to increase the specific resistance of copper 10 per cent. The field being in the main circuit remains constant. The armature current falls 10 per cent., so that the torque is reduced 10 per cent. The field of the electro-magnet also falls 10 per cent., and the resistance of the copper disk increases 10 per cent., so the Foucault currents are reduced 20 per cent., and the meter therefore increases in speed 10 per cent.

In all the meters described, so far, the speed of the motor has been controlled by some sort of brake. In a meter designed by the Author the motor is in shunt to a low resistance. The motor runs loose at such a speed that its back electromotive force is equal to the fall of pressure over the resistance. This form of meter has several advantages. The armature never takes a large current, so that the brushes are small and the friction is trifling, and mercury contacts are unnecessary. The armature is also light, as it has no copper disk, and is wound with aluminium. The chief advantage, however, is the ease of starting. Suppose the armature will start with 0·1 ampere, and suppose the armature resistance is twice the low resistance in shunt when a single lamp is turned on, taking, say, 0·3 ampere, the armature takes 0·1 ampere and starts. A brake-meter might also be made with the same resistance, and it would take 0·1 ampere with one lamp on, which in most cases would not start it; but at full load of, say, one hundred lamps, it would take the current of thirty-three, so the brushes would have to be large enough to carry 10 amperes; in fact, mercury becomes essential. The free motor meter, however, still takes only about 0·1 ampere, so its brushes can be very small strips of platinum or silver, giving little friction.

Many meters described are available for alternate currents. The Ferranti meter, for instance, is made with a laminated magnet; but, as already mentioned, difficulties arise because the torque does not vary as the current. The same remarks apply to the Teague meter wound for alternate currents.

The Thomson and the Schuckert meters are perfectly applicable to alternate currents. There is, of course, an error due to the time-constant of the fine wire circuit; but this is practically negligible. This is one of the very few meters that follows a simple law, and may therefore be considered trustworthy for alternate currents.

Many alternate-current motor meters, unfortunately, are still things that go round when the load is large enough, but whose speed does not appear to bear any simple relation to the current or power.

There are several alternate-current motors which have no electrical connection to the moving parts. Of these the best known is the Shallenberger, which has been most successful in America. The moving system is a small disk of iron. There are two coils round it, arranged at a small angle. One of these is in the main circuit, and the other is a closed coil. The current in the main coil magnetises the iron, and also induces a current in the closed circuit. This latter current lags a little. The main current, therefore, induces poles in the disk, and the secondary then acts on these poles and attempts to set the disk in a new direction, thus rotating it. The movement of the disk thus depends on angular hysteresis. If the iron is replaced by a copper disk of some thickness, Foucault currents are produced in it which convert it into a sort of solenoid, so that it is acted on in the same way as the iron, except that it moves in the opposite direction. The torque of this meter, when it has an iron disk, is thus approximately as the square of the current. Its secondary current also varies approximately as the frequency, so that the torque also varies as the frequency. If a copper disk is used, the torque varies approximately as the square of the current and as the square of the frequency, as the currents in the disk and in the secondary both vary approximately as the main current and as the frequency. The departure from the square law is because the product of the self-inductions of the open and closed circuits is much less than the square of the mutual induction. This is, of course, also the cause of the torque.

In Mr. Wright's meter the main current magnetises the field, but closed secondary coils are wound on the pole-pieces, so that the magnetization of the ends lags a little. This causes rotation of an iron or conductive disk. This meter follows the same laws as the Shallenberger, just described. In the case of the continuous-current motor meters, it was seen that the meter must either have a pressure circuit or a permanent magnet, otherwise the torque is not proportional to the current or power. In alternate currents permanent magnets are obviously useless, so a pressure circuit is necessary to give the right law. Alternate-current meters of the kind just described really require two currents differing in phase, preferably by a quarter of a period. It is not in any spirit of criticism that these remarks are offered on this and other forms of meter. It must be enormously difficult to make a meter work, whose torque varies as the square of the current, and as the frequency or as its square. In fact, a meter whose readings depend on the frequency cannot be accurate, for all the station has to do, in order to convert a heavy loss into a splendid profit, is to weaken the fields on their dynamos and run them faster. Though a station engineer would hardly be dishonest enough to run fast, he would probably be careful not to run slow. It is also but fair to mention that these criticisms are based on theoretical considerations only; the Author has no figures to show that one form of meter is worse than another.

An important class of meter consists of a clock which is made to go fast or slow by acting on the pendulum. This form of meter is also one of Professors Ayrton and Perry's numerous inventions. The best known form is the Aron meter, an instrument which has deservedly come into extensive use. In this there are two clocks carefully timed. They work an index-train by means of differential gear, on the same principle as that frequently used on tricycles. If the clocks go at the same rate, the index is not moved. One pendulum has a magnet as a bob, and this is acted on by a coil carrying the main current, so that the accelerating force of gravity is assisted. This clock then goes faster when lamps are on. This meter is not capable of the highest theoretical accuracy, because the frequency of a pendulum varies as the square root of the accelerating force, not as the accelerating force. To keep down the error arising from this, it is necessary to allow the current to modify the frequency by a very small percentage. A limit is soon reached, however, for this percentage cannot be reduced beyond a certain value, or inaccuracy in timing the clocks will cause serious errors. It must be remembered that any want of regulation of the clocks causes an error which goes on accumulating day and night, or even while the consumers are out of town. As an example, suppose a house wired for one hundred lamps, and suppose the meter calibrated to read accurately at small loads. Let the maximum number of lights often used at a time to be fifty, and suppose the meter arranged so that fifty lights alter the frequency of one clock 5 per cent. The error due to the square root law is then 2 per cent., so that the meter reads 2 per cent. wrong. Suppose the average load is equal to five lamps always on, the current has the effect of altering the speed of one pendulum ½ per cent. on an average. In order that the error due to want of regulation of the two clocks need not be more than 2 per cent., they must keep time with each other within 100th per cent., that is to say, they must keep together within one minute in a week. It is difficult to make clocks as good as this, but the makers of the Aron meter seem to have succeeded. It would be better to act on both pendulums, quickening one and slowing the other; the error could then be reduced to one-half. Attention is called to this error, because it is as well that it should be understood. Such a meter as the Aron is probably more accurate than any of the meters which involve compromises between first and second power laws.

The next class of meter is very large. A meter may consist of an amperemeter or wattmeter and a clock. The clock moves the index-train every half minute or so, and the movement is regulated by the amperemeter or wattmeter. For instance, the amperemeter may carry a snail, like that used in the striking mechanism of clocks. In a clock, the tumbler falls every hour, and the number the clock strikes is regulated by the position of the snail carried by the hour-wheel. Similarly, in the meter, the tumbler or feeler moves every minute or half minute, and its stroke, and therefore the movement of the index, depends on the amperemeter. The various mechanical arrangements for doing this are numerous; but, as they are all the same in principle, chief difficulty occurs with small loads. For instance, if a meter is to read from one to one hundred lamps, the feeler must move the train even when it has only 1 per cent. of its full travel. The stroke of the feeler at no load again must be too small to move the index mechanism. If this is driven by a ratchet, for instance, the movement must be less than one tooth. It is then difficult to arrange the feeler so as to be perfectly clear of the snail; and if it does not clear the snail at no load, it may hold it and prevent registration when a load comes on. Some designers use clocks driven by springs, and others employ electrical clocks which require no winding.

Meters of this class have been designed by the Brush Co., Messrs. Brillié, Cauderay, Frazer, Hartmann-and-Braun, Siemens, Lord Kelvin, and many others. They can be easily arranged to work with continuous or alternating currents, and can be arranged as coulombmeters or joulemeters.

There have been many attempts to produce heat-engine meters. This form labours under great disadvantages as to starting at light loads, for the power available is then extremely small, and many of these meters may be regarded as heat-engines which work through small ranges of temperatures at small loads, so that the efficiency is also exceedingly small. Professor Forbes has produced the most successful heat-engine meter. It consists of a resistance which heats when there is a current, and causes convection currents in the air. These work a small horizontal windmill, and this works the train. The power spent in the resistance varies as the square of the current, so the rise of its temperature varies as the square too if the air passing varies as the current, and the rise of the temperature of the air also varies as the current. The air will then carry off the heat at a rate proportional to the square of its speed, that is to say, at the rate it is generated. The efficiency of a heat-engine depending on small changes of temperature varies as the difference of temperature, so that the power available to expand and thus move the air varies as the cube of the current. If the air resistance varies as the square of its speed, as it is supposed to when the movement is quick enough to make vortices, the Forbes meter obeys theory accurately. It would be interesting to know what Professor Forbes has to say to this explanation, for he found the meter was very accurate, but that, according to theory, it should have been inaccurate. The energy taken to work the windmill is a very small portion of the work done by the meter. The chief difficulty is to make it start with small loads.

For instance, suppose the meter has a drop of ½ volt with 100 amperes, it then has 50 watts. With 1 ampere it has only 0·005 watt, and it is exceedingly difficult to make a windmill that will be moved by the draught caused by $\frac{1}{200}$ watt. The meter is, however, a wonderful piece of work, the windmill rotating almost without perceptible friction, and being beautifully light.

There is still one form of meter to be mentioned, and that consists simply of a clock which goes only when the consumer uses power. The consumer is then charged so much per hour for the light. This kind of meter has not any chance of wide application in this country; but Mr. Aubert's meter, which is on this principle, has had enormous sales on the Continent.

A discussion of the various uses of instruments, or practical electrical testing, would occupy too much time; so descriptions of the various methods of testing dynamo machines as to efficiency and durability, of taking the efficiencies and characteristic curves of transformers, incandescent and arc lamps, and secondary batteries, have to be omitted. To do justice to this part of the subject it would require a separate Paper.

The communication is illustrated by sketches from which the *Figs.* in the text have been produced.

[DISCUSSION.

Discussion.

Mr. G. **Berkley**, President, was sure that it would be the pleasure of the members to thank Mr. Swinburne for his excellent Paper on a most interesting subject—a Paper which would doubtless produce a useful discussion. Mr. Berkley.

Mr. **James Swinburne** said that among the instruments described in the Paper as of the Schuckert type, he ought perhaps to have mentioned one made by Messrs. Crompton, which was a modification of that type. When he wrote the Paper he knew the instrument, but did not know that it was sold so largely. He also wanted to mention a matter of history with regard to the wattmeter. It had been referred to in the Paper as if it had simply grown; but it was really invented, and it was only fair to call attention to it, as another of Professors Ayrton and Perry's numerous inventions. He had mentioned the ohmmeter as being introduced to the Institution by Lord Kelvin; but, on looking the matter up, he was not quite sure who was the inventor. From an early patent of his, in 1858, it appeared that Lord Kelvin had an instrument with a wire field; but he could not say whether it was used as an ohmmeter, or simply as a galvanometer with definite needle control. At any rate, in 1880, it was introduced as a commercial instrument for measuring resistances. Mr Swinburne.

Professor W. E. **Ayrton** considered that the Author had dealt so generously with him and his colleague, that any criticism on his part would seem out of place. But, if he ventured to point out one or two improvements that might be made in the Paper, he was sure they would not be taken amiss. It had been stated quite correctly that "a station supplying at 100 volts does not require its voltmeters to read from 10 to 150 volts, but should be provided with instruments whose whole scale is devoted to readings between, say, 97 and 103 volts, if there are no feeders." Professor Perry and he were then derided for having "devoted unlimited ingenuity to making instruments with equally-divided scales." He did not think, however, that the Author had quite grasped the fact that the very result at which he aimed—that of getting an instrument which should read over the whole scale from 97 to, say, 103 volts—could be fulfilled by an instrument which had an equally-divided scale. Among the instruments Professor Ayrton.

Professor Ayrton. on view in the library, there was one dated 1882, which had a circular scale, comprising nearly 360°, which was equally divided, the pointer going through equal divisions for equal additions of current, and also fulfilled the very aim that the Author had in view, going from one end of the scale to the other for an addition of, say, 5 or 6 volts. This was perhaps the earliest example of the type illustrated in ***Figs.*** ***1*** and *2* of the Paper. It had a soft iron needle, and the result in question was obtained by opposing the motion of the needle by a spring, and giving the latter a set, by means of a movable hand; so that the needle could start moving from zero for, say, 97 volts, and deflect over the whole circumference for an addition of 5 or 6 volts. The set could be arranged at will, and any 5 or 6 volts in the range could be selected, the pointer going through four right-angles for something like the same addition to the potential-difference. The instrument had two springs, one or both of which could be employed in controlling the needle; so that not only could the 5 or 6 volts required to move the needle through 300° be selected—for example, 20 to 26 volts, 50 to 56 volts, etc.—but the number of volts causing the needle to move through 300° could also be varied by using one or both springs. He mentioned the matter, because it would appear from the Paper that an instrument with an equally-divided scale could not be used for a central-station voltmeter to indicate between 97 and 103 volts. He might add that there was a defect in the instruments described as the ordinary central-station voltmeters of the present day, which was not possessed by the instrument of 1882. Those, for example, made by Hartmann and Braun, and others, which had a very open scale between 97 and 103 volts, and a very close scale between 0 and 93 volts, had a rather serious defect, which did not seem to have been noticed—a defect which must be possessed by every instrument of that type—namely, that an error in the adjustment of the zero made a very considerable error in the reading. It was quite easy to get several volts wrong with one of those instruments, if it were not so adjusted that the pointer was exactly where it ought to be for no current passing. That could be easily seen, from the fact that the pointer went through a considerable angle for a very small change in the potential-difference. A very small change in the force therefore made a considerable alteration in the position of the pointer; a small tilt gave a small alteration in the force, and put the pointer in a different position. With a set-up instrument, the pointer of which would make many complete revolutions in going back to zero that was not so, and a

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small error in the zero only introduced a very small error in the reading. It might, at first sight, be thought that there would be much difficulty in knowing what the zero was with a set-up instrument; but that was not the case. There were two independent pointers, one of which was moved by the current and the other by hand. All that had to be done was to put the pointer that was moved by hand to zero; the other ought to stay at zero when no current was passing, in which case they were quite sure that the instrument was properly adjusted. They then turned the pointer, twisting up the spring through a certain number of degrees, making the instrument measure an increase of 6 or 8 or 10 volts, or anything in reason, for the deflection of the pointer from one end of the scale to the other. The question of the material for springs was one to which he had devoted much attention. If steel could not be used—as was often the case, for magnetic reasons—the material which had the least sub-permanent set, he had found to be, not German silver, as was often supposed, but phosphor-bronze. There was a special kind of phosphor-bronze, which Professor Perry and he originally obtained from France, that had a very small amount of sub-permanent set. He had tried platinum and various alloys of iridium, platinoid, and other alloys, but undoubtedly the best was phosphor-bronze. The Author had referred to the difference in the extent to which various instruments were shielded from external magnetic disturbances. That was a consideration which had great weight with Professor Perry and himself, when bringing out the magnifying-spring instrument in 1882–3. If they wanted an instrument to be unaffected by external magnetic disturbances, it should have a motion of translation, and not a motion of rotation. It was a well-known principle that a uniform field, no matter how strong, would not cause a magnet to move bodily. Magnetic needles could be floated on corks in water, and they would all turn to the north, but they would not travel across the vessel in which they were floating. The Author had referred to the "twisted strip" in the Ayrton and Perry instrument. That name, however, had been improperly applied by the Author, and belonged to another and more recent arrangement, not referred to in the Paper; the instrument illustrated and described in the Paper was one with a "magnifying spring," a kind of spring whose free end rotated through a large angle for a small axial extension. The "twisted strip" was a later device: When a current was sent through the strip, it was slightly warmed, and the warming caused a great alteration in the amount of twist; so that a small current passing through the strip caused the pointer to rotate through a large angle. There was one point

Professor Ayrton. on which they were liable to be misled; viz., with regard to electrostatic voltmeters not being affected by an external field. At first sight this appeared to be right; and he was a little astonished to find one reading wrongly when near a transformer. An electrostatic voltmeter, unless precautions were taken, was comparatively easily affected by currents set up in the stationary and moving parts, due to a rapidly varying field. If the instrument were put near the transformer, it might be many volts wrong, due to the current induced in the stationary and moving parts of the metal by the rapidly alternating stray field in the transformer. The Author had referred to the split dynamometer, and had said, "On the other hand, the same instrument, arranged so as to have greater errors, and called a split dynamometer, has till lately been treated as accurate." He might mention that there was one way of using a split dynamometer shown in a Paper by Dr. Sumpner and himself, read at the Physical Society,[1] which was absolutely correct. There might be any amount of self-induction or mutual induction, or any amount of stray field in the transformer, but that particular method of using the split dynamometer was absolutely correct. It was only right to make that statement in defence of Mr. Blakesley, the inventor of the arrangement. And it was very important to bear in mind that the accuracy of the method alluded to arose from there being no self-induction to be compensated for; and not because a large non-inductive resistance was used to swamp the effect of self-induction —the condition aimed at in a wattmeter. The Author had mentioned 5 per cent. as the change in light corresponding with 1 per cent. change in pressure. He thought that was, indeed, rather a low estimate, and that it was nearer 7 than 5 per cent. The Author had made an interesting remark with reference to conservatism requiring that the scale on an electricity-meter should look like the scale on a gas-meter. Professor Perry and he had seriously erred in that respect when they devised their gaining-clock meter. They had fancied that when people had to measure something totally different from what they had been accustomed to—viz., electric energy instead of gas—they would be satisfied to use a totally different meter, but they were wrong. Dr. Aron had been wiser, and had acted on the principle of making a new thing to look very like something else that people had been accustomed to use. He might mention that the letter *l* in the words "gasalier" and "electrolier" was itself a conservatism, being the survival of

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[1] Proc. Physical Soc., vol. xi. part II. p. 176.

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the *l* of "chandelier." Of course, the right words were "gasier" and "electrier." The Author, from a feeling of modesty, had not laid sufficient stress on the novelty of his own invention—his own meter. It was an entirely new form of supply-meter, based on the use of a motor with a constant load, as distinct from one with a varying load. Hitherto, all supply-meters using motors had used them with varying load, or with resistance proportional to the velocity, or something of that kind; but the Author's meter was totally different: it was a meter in which the resistance was constant, requiring therefore only a constant current to drive it, and going at a speed which was proportional to the difference of potentials at its terminals and to the current passing through the house. It was an entirely new principle, and a very promising one. He (Professor Ayrton) had taken up the electrostatic voltmeter latterly, in conjunction with his assistant, Mr. Mather. If they could only get a good one it was far superior to any other. In the first place the great waste in power was annihilated. The most expensive voltmeters in working were the hot-wire ones. The Author had pointed out that each watt represented interest on £1 at 7 per cent. A hot-wire voltmeter of a well-known type, reading to 100 volts, required 35 watts, and when reading to 200 volts, 70 watts; so that it was a question of interest on £70 at 7 per cent. It only cost about £8 to buy the instrument, but, in power wasted, it was equivalent to an investment of £70. An electrostatic voltmeter, as was well known, could be used for alternating currents as well as for continuous currents. The first point to be considered was the shape of the needle. Most people used a flat needle, following Lord Kelvin in his quadrant electrometer, and the Author used a flat needle in his electrostatic voltmeter (*Fig. 25*). He did not think that a flat needle was the right thing, because it was not nearly as stiff as a cylindrical needle, and, therefore, the stationary parts could not be put as near the moving parts as in the case of a cylindrical needle. They could not, therefore, make a flat needle as small as a cylindrical one, and obtain the same amount of electrostatic twist; hence the periodic time could not be as small, or the instrument as dead-beat, with a flat, as with a cylindrical, needle. By using the latter form, greater sensibility could be secured, and also considerable dead-beatness and cheapness. But, when dealing with alternate-current instruments, it was necessary to have very good contact between the moving needle and the stationary parts. And, as a cylinder would be built up with spokes, and there were two sides to the cylinder, they

Professor Ayrton. had found considerable difficulty in getting good contact with rapidly-alternating currents; they had therefore devised a special form of needle, into the details of which he would not enter. There were several electrostatic voltmeters, constructed by Mr. Mather and himself, exhibited for the first time. They showed a large range and angular motion—larger than was obtained in Lord Kelvin's instrument; there was also greater sensibility and dead-beatness. One of the instruments had only a single needle, but it would easily measure down to 40 or 50 volts, and that without any magnification whatever, and it was fairly dead-beat. The result was obtained, first, by using a cylindrical, not a flat, needle; secondly, by bringing the moving and the stationary parts very near together, which could be done with a cylinder, but not with a flat needle; and, lastly, by making the stationary and moving parts of such shapes as to give a very open, and equally-divided, scale. Some instruments exhibited by him had a spring control, others a torsional control, and others a gravity control. The spring control was very convenient, because the instrument could be used in any position, and the reading could be taken with equal accuracy.

Dr. Fleming. Dr. J. A. Fleming said that he had been working a good deal with electrostatic voltmeters of the Author's construction, and could, therefore, add something on the theory and uses of that instrument to the discussion. He wished to echo Professor Ayrton's remark as to the desirability of using electrostatic voltmeters in central stations as far as possible, on account of the great waste of power involved in using any form of electro-dynamic voltmeter. The worst had not been said about the hot-wire or electro-magnetic instruments. Not only did the voltmeter itself consume a certain amount of power, but there were other sources of loss. In the Cardew voltmeter, for instance, the loss of power was from 30 to 35 watts, when working on an ordinary 100-volt circuit; but when such voltmeters were used on alternate-current circuits working at 2,000 or 2,400 volts, it was necessary to associate with them a step-down transformer, in order to reduce the pressure to about 100 volts, to bring it within the range of the voltmeter; they must therefore credit the voltmeter with all the loss incurred by the use of the transformer, which was not a light matter. An ordinary Cardew voltmeter working at 100 volts, and absorbing 30 watts of power, represented, if the voltmeter were kept on continuously, three-quarters of a unit of power lost per day in the voltmeter; and to that should be added the loss in the transformer, which

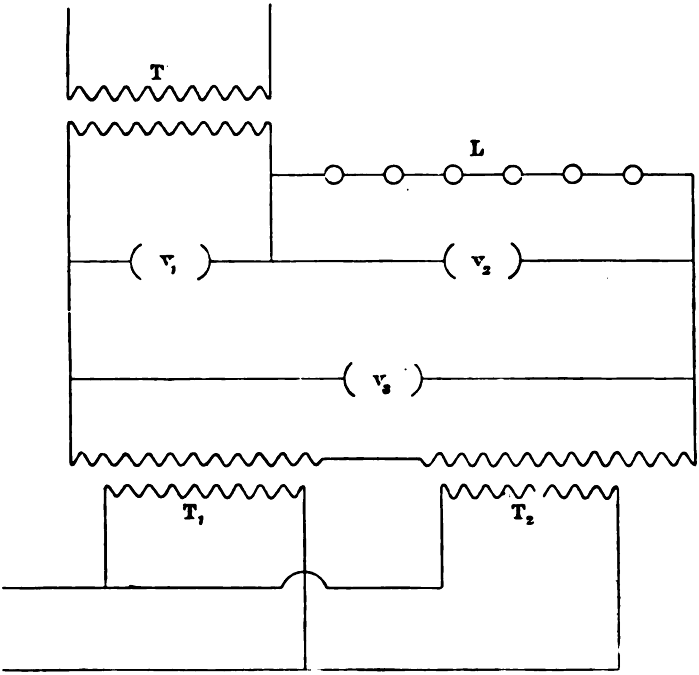
Dr. Fleming.

might be two or three times as much. In replacing these instruments by electrostatic voltmeters, there were some difficulties that he had not yet seen overcome in any instrument in the market. One was that electrostatic instruments generally had scales extending over a comparatively narrow range. Lord Kelvin's beautiful instrument, the multicellular electrostatic voltmeter, measured only from 60 to 120 volts, and the divisions on the scale were by no means uniform, but were widest at a certain point in the scale, and diminished in both directions; therefore the same accuracy of reading was not obtainable in all parts of the scale. Then there was the objection that, with high tensions, it was impossible to bring the moving system very near to the stationary part of the voltmeter, without incurring the danger of sparking across. Of course, an electrostatic voltmeter of the kind described in the Paper was nothing more or less than a condenser, one plate of which was movable; and the two plates could not be brought nearer than a certain limit without incurring the danger of a discharge from the needle to them. That limited the sensibility of such instruments. The Author had lately lent him some electrostatic voltmeters, for experiments in measuring the power taken up in the cores of transformers. They were intended to be used for 1,200 volts, but they had been pressed up to 3,000 or 4,000 volts, which was rather unfair treatment. The general course of events was that, when the observer had taken a couple of hours to calibrate the instrument, and had got it to work, a discharge passed across, burned part of the needle, and destroyed the suspension. They had, however, overcome that easily, by sandwiching the needle between two plates of mica, which extended a little over on both sides. The same result might be attained by lining the inside of the quadrants with mica. It was not found that this change introduced any difficulty, and it obviated the risk of the destruction of the interior of the voltmeter by a discharge passing from the needle to the quadrants. The question of measuring alternate-current power was a most important matter, and Dr. Fleming did not think that it had yet been satisfactorily solved. Many methods had been projected and described for measuring power taken up in an inductive circuit—a circuit consisting, say, of a large number of transformers on open secondary circuit; some of them were known to be very inaccurate, and others accurate in theory, but with many practical objections, such as being inconvenient or incapable of being applied in practice in a central station. One of these, the so-called 3-voltmeter method, was suggested simultaneously by the

Dr. Fleming. Author, Professor Ayrton and Mr. Sumpner. Theoretically, it was a perfect method; but it had the great objection that, in practice, it was necessary to have available double the working pressure. If it were required to measure the power taken up in the primary circuit in a transformer, a non-inductive resistance had to be made, of which the ohmic resistance should be approximately equal to the impedance of the primary circuit. Suppose this resistance to consist of a series of incandescent lamps, which formed a good practical non-inductive resistance; then they had to provide the means of producing twice the working pressure of the transformer. Suppose the transformer to be working at 2,000 volts in the primary circuit, they had to provide a total pressure of about 4,000 volts. Of course, the easiest way was to join up the two other transformers with their secondary circuits in series, and their primary circuits in parallel, and so to build up 4,000 volts. Then the three voltmeters had to be joined, as shown in *Fig. 26*, and the simultaneous readings taken; the result being to give, by means of a simple formula, the power taken up in the primary transformer. That method was theoretically correct, but difficulties presented themselves in practice. In the reduction of the observations, they had to take the difference of the squares of the voltmeter readings. A small error, say 1 per cent., in the reading of one instrument, would mean an error of 2 per cent. in the value of the square; and, if the errors in two readings lay in opposite directions, there might be an error of 4 per cent. introduced, even under the most favourable conditions, by an error of 1 per cent. in the voltmeter readings. Suppose it were desired to measure power coming from an alternate-current station, it could not be done by this method, because it would be impossible to provide the necessary excess of pressure. It had, therefore, been suggested to use a method which employed three amperemeters instead of three voltmeters. He had recently found it possible to reduce the number of instruments to one ammeter. The difficulty encountered was the same as in the other case, that they had to take two observations and square the readings, and take the difference of the squares; and the results, owing to errors of reading, were sometimes very disappointing, even when they took pains in the measurements. He was at present scheming an arrangement for taking the two current-readings simultaneously by a differential dynamometer of some kind; so as to read the difference of the squares of the current directly, without the necessity for making two separate observations with the same instrument. But methods of measuring inductive power had yet to be perfected.

Dr. Fleming. He could not share the view taken by the Author of the dynamometer-wattmeter, as a means of measuring power with highly inductive circuits. The general theory of the instrument was well known, and it was well known that the instrument, if calibrated by constant currents, would not give correct readings of power on an inductive circuit, unless certain corrections were made in the readings. It had been generally supposed that an ordinary wattmeter, of which the fine wire circuit consisted chiefly of non-inductive resistance, put outside the instrument, could be used for measuring power on inductive circuits; and it was known that under ordinary circumstances the reading of the wattmeter would be too large. As far as he had gone in experiments with a wattmeter of that type, comparing it with measurements by the three-voltmeter method, the watt-

Fig. 25.



3-VOLTMETER METHOD OF MEASURING INDUCTIVE POWER.

T, Transformer under test; L, Non-inductive resistance; T_1, T_2, Transformers supplying double pressure; V_1, V_2, V_3, Electrostatic voltmeters.

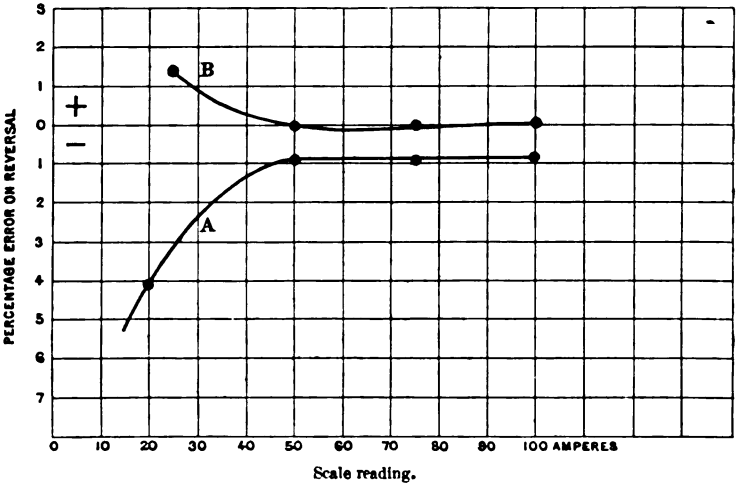
Dr. Fleming. meter very often measured too little. He had not been able to fully ascertain the reason, the researches being still in progress. He did not think that they could invariably trust to the dynamometer-wattmeter, as a means of measuring inductive power. A great deal had yet to be done in discovering the causes of error in such instruments. With regard to the subject of house-meters for alternate-current supply from central-stations, there was much to be said. It was essential to ascertain that a wattmeter, or a house-meter of any kind, to be used in measuring alternate current supply, should be one which was not affected by a stray magnetic field. There were many types of meter which, if they were put near a transformer, especially an open circuit one, would run round without any current going through them, and could be even arranged so as to go in the wrong direction and entirely vitiate the reading. It was essential to ascertain, by direct and careful experiments, whether a house-meter, in which there was a disk of metal (copper or iron), was affected in the way he had described when it was placed near a transformer with an open or closed circuit; because, if there were much stray field from the transformer, it might cause the disk to revolve in a right or a wrong direction, and the result would be disastrous, either to the customer or to the central-station supply.

Mr. Siemens. Mr. A. SIEMENS wished to say a few words in defence of the electro-dynamometer. The Author had spoken as if it were only in use on alternate-current circuits, but he (Mr. Siemens) believed that it was much used as a standard instrument, by which to correct more modern inventions, and to give them their proper bearing when they got out of order, which they were very liable to do, but which the electro-dynamometer was not. He believed it was Sir William Siemens who first suggested the wattmeter. It was one of Weber's electro-dynamometers, with one coil for the volt-circuit and one coil for the ampere-circuit. The Author had stated at the commencement of his Paper: "The vast strides made during the last ten years in the commercial use of electrical energy, are marked by departures from the practice of the experimental physicist, and approach to that of the mechanical engineer." He hoped that the electrical engineers would always measure much more accurately than mechanical engineers. That was the only way to do satisfactory electrical work—to aim at the greatest accuracy that could possibly be attained.

Mr. Evershed. Mr. SYDNEY EVERSHED said that the Author had done good service in drawing attention to the real requirements in electric house-meters. He had laid down certain conditions that all **Mr. Evershed.** indicating measuring instruments should fulfil. "For years," he said, "designers have been devoting unlimited ingenuity to making instruments with equally-divided scales." Such designers, however, he thought, existed only in the Author's imagination. All the well-known instrument-makers had, during the last five or six years, calibrated every instrument they had made, without assuming that it obeyed any simple law at all. The Author had laid down the conditions with regard to variation by temperature, and absence of errors from hysteresis, and stated that those requirements had nearly all been fulfilled by leading instrument-makers. He (Mr. Evershed) did not know whether he ought to pose as a leading instrument-maker; but he would say that some of the requirements in perfect electric measuring instruments, were far from being fulfilled at the present time. Considerable progress had been made during the last five years in eliminating the error due to hysteresis, which used to be enormous in many measuring instruments; but they were still far from perfect. In many instruments of the Schuckert pattern, his own included, that was to say, instruments in which small pieces of iron were magnetized by a coil, and the attraction of one or more of them measured—the hysteresis error did not depend in the least on the design of the instrument, but only on the length of the iron magnetized in proportion to the total magnetizing force of the coil. At high readings, anywhere near the top of the scale, errors were, as the Author had said, almost negligible; but at low readings, say, to 10 amperes in a 100-ampere instrument, serious errors were sometimes introduced. He had, during the past year, attempted to solve that apparently impossible problem of either getting the iron absolutely free from hysteresis, or compensating the instrument for the hysteresis error, and he exhibited the diagram, *Fig. 27*, showing how far he had gone. He admitted that it was not entirely satisfactory, but it was a step in the right direction. The lower curve represented the percentage error when the connections of an ordinary instrument were reversed, so as to send the current in the direction opposite to that in which it was previously going. It would be seen that, at about 10 amperes, the error was already 6 per cent. The upper curve represented similar observations taken with an instrument which was compensated for hysteresis. The error, it would be observed, was reduced from 6 per cent. to 1·5 per cent., and in the upper end of the range the error was practically eliminated; at least, they could not detect any. The method of attaining that result

Mr. Evershed. was very simple. If he diverted part of the induction passing through the fixed pieces of iron (*Fig. 7*), through a piece of iron or steel—anything which had a larger hysteresis effect than soft iron, he could so arrange matters that the induction passing through the rod by which he measured the current was constant. The only other serious error in a voltmeter was that due to temperature. He showed a curve from two voltmeters made by Messrs. Goolden (*Fig. 28*). The ordinary instrument, when put into circuit, fell in the reading, owing, of course, to the heating and the consequent rise in resistance. The lower curve showed the effect, and gave readings up to ninety minutes after putting the instrument into circuit. The total fall was 1 per cent. With the compensated instrument, he had drawn a straight line between the first observation, taken at the instant of putting into circuit, and the last, taken after the voltmeter had been in circuit for three hours. It would be seen from the diagram that all the intermediate observations fell on that line, within less than one-tenth per cent.; that is to say, within the amount of observational errors. In other words, there was absolutely no difference in the reading

Fig. 27.



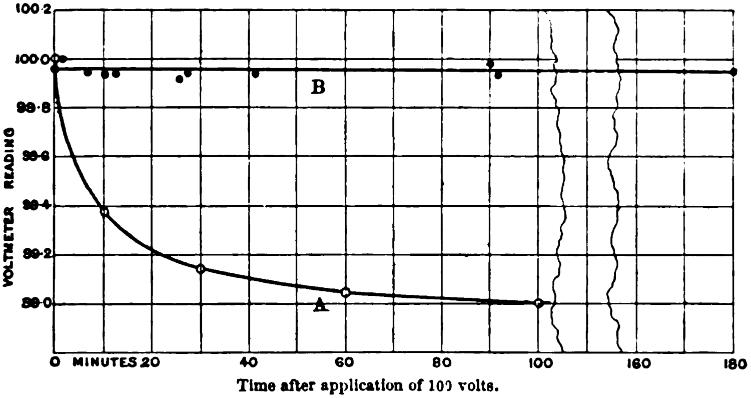
Difference in Ammeter Readings on Reversal of Current in Coil.

A, Ordinary ammeter showing effect due to hysteresis of iron core; B, Ammeter compensated for hysteresis effect.

Mr. Evershed.

of the instrument, although its temperature had risen 30° Centigrade. He thought that the descriptions in the Paper of some of the instruments were rather meagre, and in one or two cases there were slight inaccuracies. The Author had described two instruments (*Figs. 7* and *8*), one as an Evershed and the other as a Hartmann-and-Braun instrument. It would have been more correct had both been described as Evershed instruments. The Author had alluded to Lord Kelvin's lamp-counter as almost the only survivor of the tangent galvanometer. He (Mr. Evershed) had placed on the table an ammeter which he had made at the suggestion of Professor Kennedy, for the Westminster Electric Supply Corporation, to measure the leakage on circuits. As it was much on the same lines as Lord Kelvin's, he thought it might be of interest to note its use. When the Author referred to alternate-current instruments, he possibly overlooked the fact that if there were any kind of measurement which could be made by an instrument containing iron, it was the measurement of alternate-currents and alternating pressures, for the simple reason that the hysteresis error was entirely absent. He had mentioned that Mr. Evershed and he had proposed to use condensers. The Author had no doubt proposed that method, but Mr. Evershed had used it during the last two years with great success. The method was very simple, and he could not

Fig. 28.



VARIATION OF READINGS ON VOLTMETERS DUE TO RISE OF TEMPERATURE.

A, Ordinary Evershed voltmeter; B, Ordinary Evershed voltmeter compensated for temperature.

Mr. Evershed. imagine why it had not been more generally employed. A voltmeter, compensated by a condenser, would read absolutely the same with both alternating and continuous currents.

He wished to call attention to the great contrast between ordinary electrical measuring instruments and pressure-gauges. Engineers had asked him why instrument-makers could not make the one as strong and as cheaply as the other. They overlooked the fact that, in making a pressure-gauge for the boiler, they were dealing with forces of hundreds of pounds. A Bourdon tube in a cheap pressure-gauge might easily have a total pressure of 300 lbs. in it, and the torque on the axle would be something considerable —say an inch-pound. In the case of electrical measuring instruments the forces were exceedingly minute. He had recently taken the trouble to measure the torque on the axle of one of his own instruments; it was only of the order of 10 grains at a radius of half an inch; and it would easily be understood that the difficulties of getting rid of friction in dealing with such small forces, were very considerable. He thought that sufficiently met the view of those who considered that there was no more difficulty in making a voltmeter, than there was in making a pressure-gauge.

With regard to meters, the difficulty in making an electric house-meter was solely one of power. They were so accustomed to measure gas and water by meter, and to have practically no restrictions with regard to the power employed, that they were apt to lose sight of the fact that the whole difficulty in measuring electricity was due to the circumstance that they could not afford to lose any volts in the meter, while the current was on its way to the house; nor could they waste more than a-tenth of an ampere, at most, in a shunt across the mains. There were very few meters in the market which would stand such rough usage as a gas- or water-meter. He had occasion, a few months ago, to see a water-meter tested, in the case of a disputed account. The meter had been put in a pit, frozen several times, and subjected to most severe treatment, from an electrician's point of view; yet, when tested, it indicated correctly within 2 per cent., and that was after six years' use. He did not think there was any electric meter which would last six months under those conditions; and, until they could get a meter which would last, not six months, but six years, he did not think inventors could claim to have made any great advance towards perfection in electric-supply-meters.

Mr. Kapp. Mr. Gisbert Kapp said he should like to correct the drawing in *Fig. 15*, representing an instrument designed about nine years ago by Mr. Crompton and himself. The drawing was one of the first type, but it was not a satisfactory instrument. The coil C was Mr. Kapp. not set at right-angles to the line joining the poles of the electro-magnet, but at an acute angle; and by that means they were able to obtain a scale of about 90° opening—in fact, a very readable scale. He mentioned the matter, because, if any one tried to make an instrument like that in *Fig. 15*, he would not find it satisfactory; he must swivel the coil first. In dealing with the question of indicating instruments, it was impossible to cover the whole ground in so short a Paper. The Author had left out one consideration which was of some practical importance, that of getting a current-indicator or ammeter which should not swing too much. He had taken great trouble to obtain an ammeter for gas-engines, and all the English makers to whom he applied had said that they could not produce a properly damped instrument, the needle of which would stand practically still whilst the impulses from the engine came and went. He had met with no success until he applied to Mr. Evershed, who had put on a damping arrangement that was so simple, ingenious and effective, that he would describe it. The damping arrangement consisted of a light rectangular piece of iron wire, which was pivoted on fine points, and hung just in front of the needle. If the current-impulse came, the iron was drawn up against the needle, and so created momentarily sufficient friction to prevent the needle from swinging out too far. It was a very simple arrangement, costing only a few shillings, and members would be glad to know, that, if they were troubled with ammeters which swung too much to give accurate readings, they could correct them by that contrivance. The Author had laid great stress on the necessity of supply-meters being absolutely reliable, especially as a meter which was made for forty or fifty lights, was generally worked with a much smaller number—ten or fifteen—and, having a small current passing through it, the power available for working it was very small. If the meter were of the pendulum type, first introduced by Professors Ayrton and Perry, it might register backwards when no current was passing. That had happened in his own case. He had a meter in his office, which, during the last few weeks, while he had not used the light, had actually registered backwards; so that the Company would have to pay him, instead of his paying them. The inspector had been several times to see it, and had at length set it right. The meter was perfectly set; he had checked the two pendulums for days together, and they swung absolutely in unison; but, after six months, it was found that they had to be re-set. In that respect a

Mr. Kapp. meter of the motor type was far preferable, because it could never go unless the current passed through it. It was possible that it might not go if a small current passed through it; but it would never register either forwards or backwards when no current was used. A meter of that kind would never be unfair to the person supplied. It might be unfair to the Companies, but it was to their interest to keep meters right. On the whole, therefore, he preferred the motor meter to the pendulum meter. Of course, they all wanted accurate meters, but there were cases in which it was an advantage to have a meter that registered far from the truth. If, for instance, the meter could be made untruthful during the day, charging the units consumed between certain hours at a lower rate, it would still be to the advantage of the Company to accept such a reading, because it would induce consumers to use more energy in those hours during which the load coming from the station was now very small. Vestries had considered the question, and were very desirous of getting cheap electricity in the daytime, when, as a rule, people did not want light, except in dark passages and underground rooms. They would rather encourage the use of motive-power, but, if eightpence per unit were charged for motive-power, each horse-power, if used ten hours a day during the year, amounted to about £70; whilst with a gas-engine, one horse-power could be obtained for £25 or £30 a year. It was hopeless to expect electricity to be used for motive-power purposes on any large scale, or continuously, unless it could be supplied at a price approaching that of gas. Of course, some little additional charge might be made for the great convenience of having an electric-motor instead of a gas-engine. If the companies could afford to sell the electricity at 3*d.* or 4*d.* per unit, instead of 8*d.*, and could sell it steadily all day long, he would suggest that some arrangement should be made by which the meters should be automatically caused to register at a lower rate during certain hours, and then at the full rate allowed by the Board of Trade during the lighting hours. In that way they would encourage the use of electricity for motive-power and other purposes, and increase the revenue of the Companies, without increasing the maximum evening load.

Mr. Crompton. Mr. R. E. B. CROMPTON desired to supplement the Paper, by giving a short description of the method of electrical testing employed by his own firm, in common with others, for obtaining accurate electrical measurements—such as those necessary for obtaining the efficiencies of electrical machinery, dynamos, motors and the like; and also in actually standardizing

Mr. Crompton

the instruments they manufactured and sold. They commenced by using several of the forms of commercial instruments that were in the market, but soon found that, although such instruments were extremely accurate under certain conditions, they were not sufficiently accurate under the conditions in which they had to be used in engineering works, or at central-stations for the supply of electricity. In both cases, the readings of many of the best instruments were liable to be disturbed by the stray magnetic fields of varying strength, which were always met with in such workshops; and it was necessary to have a standard form of apparatus free from this defect, which could be thoroughly relied upon. It was principally owing to Dr. Fleming that he began what had been called the potentiometer method of measurement. The arrangement is shown diagrammatically in *Figs. 29* and *30*. The potentiometer itself consisted of a wire AB stretched over a frame. The wire was made of an alloy of platinum and iridium, and was extremely hard. Great pains had been taken to ensure that it was accurately drawn, and the alloy well mixed, so that the electrical resistance per unit of length was very constant. It was a mechanical engineer's job, after the wire had been put in position on the instrument, to calibrate it. It was much the same thing as scraping up a surface-plate. The parts where the resistance was lowest had to be brought up to the standard; by slightly reducing the gauge at those points by rubbing, the whole wire was brought to an extremely high degree of accuracy. The following was the way in which the instrument was used. It was supplied with a constant current by means of a small secondary battery consisting of three cells in series; in this circuit there was also a variable resistance, which was made so that it could be readily adjusted to reduce the electromotive force of the three cells so as to give a difference of potential of 4 volts at the ends of the wire. C was a contact-slider connected with a wire from the galvanometer, and having a knife-edge to make contact on the wire A B at any desired point in its length. The galvanometer was preferably a sensitive one of the Deprez d'Arsonval dead-beat type. A multiple switch, so arranged that the numbers of pairs of contacts on it corresponded with the number of electromotive forces X, Y, Z, &c., required to be measured. One of these electromotive forces should be the standard with which it was desired to compare the unknown electromotive force. The standard generally used for this purpose was the well-known Clark cell, which was considered to give a definite electromotive force of 1·4380 legal volts at 15° Centigrade.

Mr. Crompton. As the electromotive force of these standard Clark cells varied with the temperature, it was usual to mount them in a stand provided with a thermometer which indicated the actual tempera-

Fig. 29.

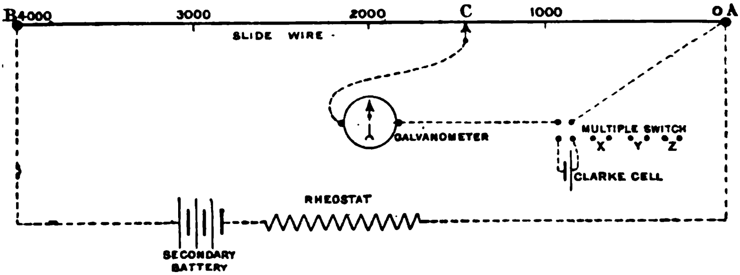
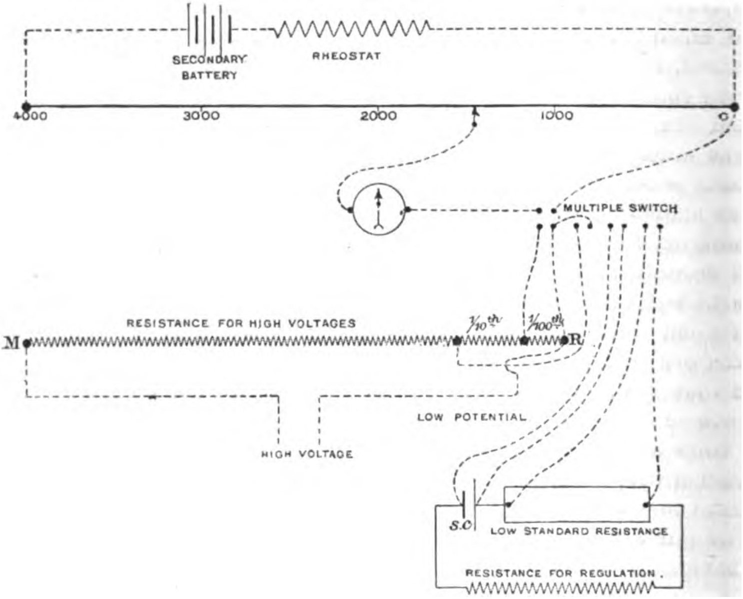

B
4000
3000
2000
C
1000
O
A
SLIDE WIRE
GALVANOMETER
MULTIPLE SWITCH
X
Y
Z
CLARKE CELL
RHEOSTAT
SECONDARY BATTERY

Fig. 30.


SECONDARY BATTERY
RHEOSTAT
4000
3000
2000
1000
O
MULTIPLE SWITCH
RESISTANCE FOR HIGH VOLTAGES
1/10th
1/100th
M
R
LOW POTENTIAL
HIGH VOLTAGE
S.C
LOW STANDARD RESISTANCE
RESISTANCE FOR REGULATION

Method of Taking High Voltage Readings; also of Measuring Currents and Low Voltages.

ture of the cell itself. A table was attached, showing the electromotive force of the cells to five places of decimals, for each degree of temperature. In order to measure electromotive forces

Mr. Crompton.

up to 4 volts, the contact C was first placed at a point on the scale corresponding with the temperature value of the Clark cell at the time the measurement was made. For instance, if the temperature were 15° Centigrade, the corresponding value of the Clark cell being 1·4380, the contact was placed at 1,438 scale divisions measured from the point A. The standard Clark cell *s c* must then be switched in by the multiple switch, and the variable resistance adjusted, until no current passed through G when the contact C was pressed down. This was called balancing the Clark cell. It meant that the electromotive force at the point C, or the potential difference between A and C, was exactly 1·438 volts, corresponding with 1,438 scale divisions; therefore each scale division was $\frac{1}{1,000}$ volt, and division 4,000, at the terminal of the wire, was exactly 4 volts. To measure any desired electromotive force, X or Y, those must be switched in so as to take the place of the standard cell. The slider was then moved until the galvanometer again came to zero, showing that no current was passing through it. The reading taken at the contact point C, in scale divisions, was the actual reading in volts. When measuring from 1 to 4 volts, it was necessary to put the decimal point three places to the left. For instance, if the reading were 2,020, it would represent 2·02 volts. For measuring electromotive forces greater than 4 volts, a multiple resistance M R, of about 5,000 ohms, was used. This had intermediate contacts, so arranged that the potential difference could be measured at any desired decimal fraction of the total potential difference between the extreme terminals of that resistance. It was generally found sufficient to take such fractions as $\frac{1}{1,000}$, $\frac{1}{100}$, and $\frac{1}{10}$. As a potential difference up to 4 volts could be measured on the potentiometer itself, if this were taken over $\frac{1}{1,000}$ of the total, it was evident that the total potential difference at the terminals of M R must be multiplied by this figure—that was, that 4,000 volts could be measured. For measuring currents, the potential difference was taken at the terminals of resistance, which were generally either 1 ohm, $\frac{1}{10}$th ohm, $\frac{1}{100}$th ohm, $\frac{1}{1,000}$th ohm, &c. Up to 4 amperes, the ohm was used; up to 40 amperes, the 10th; up to 400, the 100th, &c. In this case also, the readings of the instrument were taken directly from the scale divisions, the position of the decimal point being moved to the right as each lower fraction of the ohm was used. When very strong currents were measured by taking the potential difference at the terminals at low resistances, it was of great importance that the fractions or sub-multiples of the ohm used, should be so contrived as to be not heated by the current passing

Mr. Crompton. through them. The matter had lately been expressly urged upon his notice. It was found that, in order to get great accuracy with air-cooled resistances, the apparatus became bulky, and even then the temperature errors were serious. He had contrived a method of enamelling, to protect the resistances from the action of water, and cooled them by water-circulation round them. In that way he had contrived resistances of very moderate size, which could be kept at a constant temperature, even though large currents were passing through them. The accuracy of measurement obtained in that way was surprising. It was possible to compare differences of potential to within 1 part in 4,000. The instrument could also be used for making almost any kind of comparison where continuous currents were used. It had the special merit that it could be taken abroad to any part of the earth, and it could be repaired *in sitû*. There was no delicate part about it, and, if the calibrated wire were destroyed, it was possible for the operator himself to make a new one. All that was necessary was to rub or scrape the wire so that the resistance per unit of length was equal from end to end, and that could be tested and adjusted on the instrument. In that respect it differed from all the other forms of apparatus which depended upon delicate adjustments; and which, after having been damaged in transit or in other ways, had invariably to be sent back for re-adjustment and re-calibration. The only re-calibration required in the instrument he had described, was after the replacing of the wire; all the rest of the instrument was fixed. It had no moving parts, pivots, or delicate springs to be corroded or damaged, such as there were in all the other forms of instruments that he knew.

Lord Kelvin. LORD KELVIN said it was, of course, impossible to present a thorough treatment of the subject in so short a Paper, but as a record, or an index, of what had been done it was very comprehensive. The various principles that had been adopted for electrical measuring instruments had been touched upon in a fair and appreciative spirit. The Author had remarked, with reference to his (Lord Kelvin's) multi-cellular electrostatic voltmeter, "This instrument has a horizontal dial, but it is provided with a mirror, so that the readings are visible in front, if it is on the level of the eyes." Although by this method readings could be taken with fair convenience, he still felt that, especially for a central-station of electric lighting, it would be an improvement if the mirror could be done away with, and the instrument made to show at once on a vertical scale. He had therefore introduced a modification, which

Lord Kelvin.

had only been finally tested in his laboratory a few weeks ago. It gave its readings on a vertical cylindric scale, which could be read at distances of many yards. There was another point against the electrostatic voltmeter, which the Author had not mentioned, but which he thought was of some importance—the provision of some automatic checking arrangement, so that the instrument would be practically dead-beat. He had found that that could be done in the simplest manner by a well-known expedient, corresponding to the dash-pot in engineering. Without disturbing the general structure of the instrument, he could readily hang a vane on to the lower end of the stem that carried the needles; and that vane working under oil, was so arranged that it produced a practically dead-beat instrument. The Author's remarks upon the subject of the measurement of electric activity were very important, and ought to be taken to heart. There was a general impression that a wattmeter for alternate currents was impracticable without a certain complication of scientific adjustment which the Author had described. The Author, Professor Ayrton, Mr. Sumpner, and Dr. Fleming had gone into the subject in a very thorough manner, and had brought out scientific developments of remarkable and interesting character. He nevertheless heartily concurred with the Author's remark—"It is, however, useless to employ complicated methods of measuring power when a simple one is better. The prejudice against the ordinary wattmeter has no real foundation." Let the fine wire coil of the ordinary wattmeter have a sufficient anti-inductive resistance in its circuit, to produce the result that the current through the fine wire coil should be, nearly enough for practical purposes, the same as it would be were there no inductive impedance, and were there no effect of inductive action from the fixed coil upon the movable coil: these conditions being fulfilled, the wattmeter's measurement of activity was correct. The Author had rightly remarked that, "if any one will take a real instrument, designed with a little care, and substitute the approximate values of R and L, he will find that he has been straining at a gnat." He might have added, "and swallowing a camel," taking into account the very difficult methods adopted to avoid the inconveniences arising from the action of that gnat. The fact was that, with a judiciously-arranged wattmeter, there was no difficulty whatever in rendering the error due to the quasi inertia of the electric current, when the wattmeter was applied to an alternate current, practically insensible. They had always the means of testing whether it was or was not insensible and of ascertaining its value in the latter case. There was

Lord Kelvin. one difficulty which the Author had not thoroughly dealt with, although he was quite aware of it. This was, however, perhaps the most serious difficulty in connection with wattmeters for alternate currents—namely, the law of distribution of the electric current in the conductor. When conductors were too thick to allow the effect of their current to be calculated as if it were a current in an infinitely thin line, like a wire in an ordinary coil, then an exceedingly difficult subject for mathematical investigation came before them—the law of distribution of the current in the thickness of the constructor. He would not enter into that subject, which would require very elaborate treatment; but would merely say, that the wattmeter ought in every case to have such an arrangement of the thick conductor for carrying the main conductor, that the difference of distribution of the current, for different frequencies of alternation, should affect the result as little as possible. There were ways of doing that which he had discussed with the Author many years ago, and he would not then enter into the question. He had pointed out that any such arrangement was, after all, only an approximate elimination of error; the degree to which it was eliminated could always be ascertained by experiment; and at the worst, a wattmeter might require correction according to the frequency of the current for which it was used.

Mr. Preece. Mr. W. H. Preece desired to make one or two remarks from quite a different point of view, namely, from that of the user of electric light. Engineers were in the habit of applying various processes to add to their comforts. They warmed their houses, and they took care to place thermometers in the different passages and rooms, to see if the warming apparatus behaved properly. On the other hand, most of them at present—he hoped it would not be for long—used gas for lighting; but how many of them were there who fixed pressure-gauges in convenient places in their houses, to tell them how the Gas Companies behaved, and how they maintained their proper duty? They wanted to do the same sort of thing with regard to electricity; they wanted to find out whether the electric-lighting companies, who had taken parliamentary powers to supply them with electrical energy, performed their functions and discharged their duties properly; and they could only do so, by having instruments in their houses of such a character as those described by the Author. The voltmeter which would tell them at all hours of the day the electrical pressure entering their houses, was a most convenient instrument, and it had the merit of having an taker was destroying their lamps or maintaining the life of those lamps. The eye was such a remarkable instrument that, while it could not detect the variation in light, it adapted itself with wonderful rapidity to change of light; and it was quite possible for any one to sit under the influence of a lamp which at one moment gave 20 candles and at another moment 10 candles, without being aware that any change had taken place, if a certain amount of time had elapsed between the two changes. The standard lamp which was generally supplied was a lamp that was said to give 16 candles with a voltage of 100. He believed that it might be reasonably accepted that a lamp supplied for 16 candles at 100 volts, would give 16 candles when new. By the regulations of the Board of Trade a certain variation of pressure was allowed on the part of the Supply Companies; but they could not know what that variation was, unless they put in their halls, or in some convenient place, a voltmeter that would tell the changes. Let them see what those changes meant. There was one law connected with the production of light by the current which was very well established, namely—within the range of the authorised variation of the voltage, the light given by a lamp varied as the sixth power of the current.

The accompanying Table gave these variations for two cases:—

TABLE.

100-Volt 16-Candle-power Lamp.		50-Volt 8-Candle-power Lamp.	
Voltage.	Candle-power.	Voltage.	Candle-power.
96	12·52	46	4·85
97	13·33	47	5·52
98	14·17	48	6·26
99	15·06	49	7·09
100	16·00	50	8·00
101	16·98	51	9·01
102	18·02	52	10·12
103	19·10	53	11·35
104	20·25	54	12·69

With 100 volts and a 16-candle lamp, it would be seen that, vithin a range of only 4 per cent. on each side, there was a drop n candle-power from 20 to 12 candles. That difference might go on in their houses without the eye having the least idea that uch a change had taken place, owing to the remarkable power

Mr. Preece. possessed by the iris, to expand and contract with the variation of light. If they could encourage the electric-lighting companies to lower the voltage without reducing the light, they would increase the life of the lamps to a remarkable extent. If, on the other hand, through any mistake, they raised the voltage to over 4 per cent. above the standard, there was a strong probability of the lamps being smashed—a thing that often happened. Those figures showed what took place when dealing with 100 volts. But there was a practice in vogue in isolated installations, of endeavouring to work the installation with smaller voltage; because, where they had isolated installations, they used batteries as a rule, and desired to diminish as much as possible the capital expenditure in the supply of batteries; they accordingly reduced the number, and tried to work the installations with 50 volts. Coming to 50 volts, and taking, not a 16- but an 8-candle lamp, if they made exactly the same variation of voltage at 50 volts, they found that with the same variation they might at one time have an 8-candle lamp giving 12·69 candles, and at another time giving only 4·85 candles; so that a variation of 4 volts on each side made a marvellous change in the light produced. Those who were in the habit of using batteries knew that, after a battery had been drawn upon for two or three days, its potential fell, and the useful rate of a battery was generally determined by a fall of voltage of 10 per cent. Supposing they had their houses fitted with 10-candle lamps, and they allowed a fall of voltage of 10 per cent., it meant that the lamps which, when fully charged, gave 10 candles, gave only 5 candles when the voltage fell 10 per cent. The moral to be drawn from that was, that it was better to use as many batteries as possible, and to fit up their houses with 100 volts rather than with 50 volts. He would like to say a word also about the unit adopted by the electric-lighting companies, when charging for the supply of the current. The unit of electrical energy was well defined by Act of Parliament, but the word was very loosely used, even by such an accurate writer as the Author; in one part of the Paper the Author called the Board of Trade unit simply a unit, and spoke of charging 2*d.* per unit; whereas, two or three pages further on, he spoke of a charge of 2*d.* per kilowatt-hour. The unit by which gas was charged was 1,000 cubic feet; Water Companies charged by the thousand gallons; and electricity was charged by the thousand watts consumed per hour. Those who were in the habit of applying that new scientific term to power, had not the least difficulty in knowing what was meant by the number of watts consumed in a lamp. At present there was no name attached to that unit. It might also be said that there was no name attached to the unit of gas or of water; but it became very awkward, when dealing with a new idea like that of electrical energy, to have no name; and there was a strong desire to introduce some name to express the unit. They had ohm, volt, ampere, and colomb. He had on one occasion proposed a name, but, as it was received with a great deal of ridicule, he discarded it at once. The name that he wished to see applied to that unit was itself a new invention. It had never been applied as a scientific term; it had not long been known to the scientific world; but it had been accepted by universal acclamation. When the name was attached to that scientific unit, there would not be much hesitation in accepting it. The name which he suggested was "Kelvin." There was one statement in the Paper to which he took exception. The Author had stated that the only survivor of the tangent galvanometer was to be found in Lord Kelvin's lamp-counter. If he were to cast his eyes around the world, he would find at that moment more tangent galvanometers in practical use in electrical engineering, than were to be found in all the voltmeters and ammeters and all the other meters that were used in electric lighting. **Mr. Preece.**

Mr. James Swinburne, in reply, said that he feared his remarks about equally-divided scales had been misunderstood. Other things being equal, an equally-divided scale might be useful; but, unless an instrument naturally followed a straight line law, it was a mistake to try to make it do so artificially. The scale should be engraved to suit the instrument; the instrument should not be tampered with, to make it fit the scale. Referring to the question of cylindrical *versus* flat plates in electrostatic instruments, he thought it really depended upon whether they were working with low or high pressures. For low pressures, such as 100 volts, they must have the best workmanship, and get the plates as close together as possible. In that case he thought that the cylindrical form was best; but, when dealing with 2,000 volts, they were not limited by the workmanship, but by the sparking distance. That was important in connection with high-pressure instruments. At first sight it might appear easy to make an electrometer for very high pressures, because the forces were so large, but, unfortunately, the distances also were very large; so that the forces were small after all. The result was that so much was not gained on reaching high pressures. To make an instrument for 2,000 volts, was not, except as regarded workmanship, **Mr. Swinburne.**

Mr. Swinburne. easier than to make one for low pressures. Several speakers had pointed out that he had not referred to the quality of dead-beatness in instruments. Of course dead-beatness was very important indeed. With regard to the springs, it was interesting to know that Lord Kelvin found platinum-iridium best. Mr. Siemens had referred to the Siemens dynamometer, as being an instrument commonly used as a standard to check other instruments. Lord Kelvin's balances were all dynamometers. He did not know about the Siemens dynamometers made lately, but the early instruments were certainly not accurate enough for testing, and using as standards. He had had an instrument for two or three years (it was not new) which gradually fell about $\frac{1}{4}$ per cent. per month; that was to say, the reading increased $\frac{1}{4}$ per cent. per month. The spring was steel, gilt. He did not know whether gilding injured the springs, but he thought it very likely, owing to occlusion of hydrogen by the iron. In his own experience he had found phosphor-bronze to be the best; as Professor Ayrton had pointed out, it seemed to have no sub-permanent set. Referring to Mr. Kapp's instrument, the Paper was only intended as a sort of *résumé*, and it was impossible to do more than give diagrammatic sketches, explanatory of the principles, and not the details of construction, of the various types of instrument. He did not mean to represent any actual form of Mr. Kapp's instrument. He had a great many forms, and he was one of the first to use the skew principle, to obtain a large reading. He had only illustrated the form that he thought would be the easiest to explain in a few words. He was very glad, and he thought it was very important, to have Lord Kelvin's opinion on the question of wattmeters. He certainly felt that the wattmeter had been a neglected instrument, and that it was infinitely better than the various complicated methods which were supposed to replace it. Non-inductive resistance would always swamp the inductive effect of the coil. In a well-designed wattmeter it was so small that it was not worth swamping. They need not, however, go into that subject, but he might point out that in all methods of measuring power, whether by electrostatic voltmeters, or dynamometers, or any current instrument, they had to compare a pressure and a current; and they must therefore have non-inductive resistance somewhere, and they were always limited by the accuracy of non-inductive resistance. If it were made non-inductive enough to act in one case, it would act in any other case. The inherent errors were the same, but the accidental errors, due to such methods as measuring two very large quantities and taking their difference, were infinitely

Mr. Swinburne.

greater. It might be thought that he had said little about many of the instruments. He had mentioned comparatively few of Lord Kelvin's, and had omitted some of the instruments of Professors Ayrton and Perry. But it was impossible to describe all the instruments of inventors like Lord Kelvin, seeing that they brought out a new instrument almost every week. He had, therefore, only described one or two, which he considered representative. In the discussion of various meters, he had called attention to the possibility of all index mechanism, or all metal work other than iron or nickel, being attacked by mercury, or mercury vapour. He had received a letter from Mr. Hookham, an authority on such matters, stating that the evaporation of mercury would not affect even brass index mechanism, provided that there was no contact. Contact with mercury would destroy any brass or copper work, but mercury vapour would not do so. That was very important, because it was the only objection that he could see to such meters as Professor Perry's or Mr. Ferranti's. He believed that Mr. Hookham had a new one of the same kind, and that other people were making similar instruments. Mr. Evershed had said that hysteresis did no harm in alternate-current instruments. He thought, however, that the statement in the Paper was correct; namely, that an instrument which had hysteresis errors with a continuous current would be inaccurate, though not to the same extent with alternate currents. If the force were proportional to the product of the instantaneous current and the induction, and if the induction were not proportional to the current, both rising and falling, there would be an error. Lord Kelvin had pointed out to him that it would have been more accurate to have said that a correction for this should be made, as the effects can be foretold, and can be allowed for in calibrating the instrument. Mr. Kapp's proposal to use meters which registered slowly during the day was most important. There might be difficulties in designing such meters. One method that occurred to Mr. Swinburne was to use higher frequencies during the evening than during the day, and to employ meters which depended on the frequency. This arrangement would be, of course, only applicable to alternate-current systems; and, as yet, there were no alternate-current motors in the market. But, in the future, when motors came into use, it is probable that low frequencies would be advantageous in their case, though it was a serious drawback in the case of transformers. Mr. Preece had referred to the tangent galvanometer. He could only say that if the Post Office used such a large number of tangent galvanometers, he would recommend it to alter

Mr. Swinburne. that practice. He would mention, before concluding, that Mr. Roux had placed one of Mr. Brillié's newest meters in the Library.[1] It was a very interesting type of joulemeter, and was the only motor meter, in commercial use, which was independent of errors arising from the variation of frictional resistance.

Correspondence.

Professor Thomson. Professor Elihu Thomson desired to draw attention to a necessary correction in relation to the instrument illustrated in *Fig. 16*, which had been invented by him. The Author had said "The needle A is a sort of fork of soft iron, and it tends to move round to the narrower part of the conductor, where the field is stronger." This was not quite correct. The little iron fork, or horseshoe, which was made very light, and the motion of which was opposed by a small weight carried on a radial arm extending from the axis, did not tend to move round to the narrower part of the conductor; but actually moved from the narrower to the wider part of the conductor, on account of the eccentricity of the axis or support of the needle in its relation to the single turn of conductor. The object of varying the width of the conductor in the instrument was not to concentrate the field, as suggested by the Author, but in order to render the readings on the scale more nearly proportional to the current intensities, *i.e.*, to make a proportional scale, as it had been found that a plain ring gave but slight deflections for weak currents, and gradually increased the deflections for stronger currents. By shaping the conductor so that it gradually widened in the direction of the stronger currents, a close approximation to proportionality in the readings was obtained. The advantage of the instrument was its simplicity and ease of construction, and the fact that it could be made to respond to very strong currents, whilst still maintaining fair accuracy with very moderate currents. Instruments were also in extensive use based on the same principle, but in which the conductor had several turns instead of a single turn, and in which the section of the conductor was uniform in the periphery of the coil. These instruments were largely used as indicators for both continuous and alternating currents. The same instruments, wound with finer wire and used in series with a non-inductive resistance of con-

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[1] Minutes of Proceedings, Inst. C.E., vol. cviii. p. 504; *The Engineer*, May 13, 1892.

Professor Thomson.

siderable amount, were employed as voltmeters for both continuous and alternating work. With regard to the comments made by the Author upon the motor meter manufactured by the Thomson-Houston Electric Company, one of the chief considerations which led to the development of this meter by Professor Thomson was, that it was found desirable that the meters should be applicable to both alternating and continuous currents, and that they should register the energy consumed rather than the coulombs passing. In the case of the use of alternate currents, where reactive coils were employed for modifying the delivery of energy, the meter should deduct any return of energy due to self-inductive load. This was true also of alternate-current motors. Any meter which responded only to the current utterly failed to register returned energy; but, on the other hand, registered energy which had been sent out, and again on its return by self-inductive loads, thus making a double charge for what the customer had not received at all. It might also be added that the drop in the series coil of the motor meter in question was believed to be very small, and that further improvement in this respect was scarcely necessary. When it was remembered that meters were manufactured which responded to as many as four hundred or six hundred lamps, and were yet sensitive to a single lamp without a high percentage of error, it would be seen that the instrument had reached a fairly advanced stage of development. Cut-off magnets had also been made for opening the circuit of the fine wire or shunt circuit passing through the armature of the meter; the turning off of the last lamp breaking the fine wire circuit, and the turning on of a single lamp or more remaking this circuit. Were it not desirable to keep down the cost of production of the meter, it would be possible to make the instrument of greater refinement. This was not, however, needed in actual commercial practice. The meter had also been made from the first to act as a coulomb-meter, by the use of electro-magnets instead of permanent magnets to affect the damping disk; and in this respect was like the Hummel meter alluded to by the Author. It might be added that the Thomson motor meter had been so modified as to be applicable to the case of arc-lamps in series, and to respond to variations in the voltage. In this case, the armature part of the meter received a constant current in shunt to a small resistance in the main line, while the field-coils of the meter surrounding this armature were of fine wire in shunt to loops of eight or ten arc lamps, and the registration obtained was in proportion to the difference of potential between the ends of the series of lamps.

Mr. Roux. Mr. G. P. Roux observed, with reference to the first point to which the Author had directed attention, that a meter that would not register accurately all intermediate loads was not worthy of the name of meter. That was, however, the chief defect of many of them. Nevertheless, in practice, a certain error had to be allowed, but should not exceed 2·5 per cent., which was the allowance made in the case of gas-meters. The second point bore upon the ordinary inertia of meters which did not start with weak currents. Numerous experiments, made by himself, had convinced him that the majority barely started with one-tenth of the total load, and then with an error of at least 10 per cent. In other words, a 10-ampere meter started with 1 ampere but only registered 0·9 ampere, beyond which the starting was not always certain. One meter alone, to his knowledge, was without that defect. The Brillié meter,[1] with which many experiments had been made, and which he had himself tried for nearly a year, started with certainty at one-thousandth of the total load. The trials that he had made were with a continuous-current meter with 10 amperes at 100 volts. It was guaranteed by the inventor to start with 0·1 ampere, and actually started with 0·01 ampere. Although necessarily inaccurate at that point, there was no real drawback, for one never had to measure such weak currents. At and above 0·1 ampere, it was absolutely accurate up to 12·5 amperes, which was 25 per cent. above its range, and it started at 38 volts. Variations of potential and current of one-tenth per cent. were recorded with a high degree of sensibility. A meter of this type, designed for 2,000 amperes, started with 2 amperes as certainly as with 100. The meter belonged to the class of motor meters, its essential part comprising a movement, the speed of which was proportional to the strength of the current to be measured. Unlike all other motors of this class, the rotation was effected by a motor, whilst the measuring apparatus consisted of an electro-dynamometer that regulated the speed of this motor. The movable coil of the electro-dynamometer carried suspended a disk of red copper, which was enclosed by two sets of permanent magnets, whose opposing poles on the two faces of the disk caused a magnetic field to cut it. This arrangement of magnets turned under the action of a small electric motor. When the current passed, the electro-dynamometer left its equilibrium position and turned the disk through a small angle; the magnet arrangement, on the other hand, began to rotate, and exerted a force tending to restore

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[1] This instrument was described and illustrated in *The Engineer*, May 13th, 1892.

Mr. Roux.

the disk to the position it had left. The force thus exerted was proportional to the speed of the magnets. This speed was regulated by means of resistances in the circuit of the little motor, introduced and withdrawn by the electro-dynamometer. If the speed was too low, the electro-dynamometer was not brought up to the zero; if, on the other hand, the speed was too high, it passed the zero and exercised a retarding influence. A condition of equilibrium was set up when the attraction of the magnets equalled that exercised by the electro-dynamometer. In actual operation, this condition obtained at each instant, and the speed was continually proportional to the quantity E × C which it was required to measure. Errors due to temperature were absent, owing to the copper disk being of the same metal and conductivity as the coils of the electro-dynamometer; consequently the variations of temperature were the same in both. An experiment had been made in order to ascertain whether variations of temperature could distress the meter. To this end, one had been subjected to a constant temperature of 60° Centigrade for a period of three days, and afterwards re-verified, its indications proving undisturbed. With regard to the consumption of energy by the meter for its own work, that was, in his (Mr. Roux's) opinion, a most important matter, and one which should be taken into consideration in purchasing these instruments. He thought that the consumption of the Brillié meter was exceedingly slight, by reason of the high resistance (10,000 ohms) of the electro-dynamometer coil, which was always in circuit. Indeed, for a station working at 100 volts, there would be a continual expenditure of only 1 watt. The consumption of the motor was proportional to the load, and about 3 watts for the full load—a quantity quite negligible in view of the existence of meters which consumed at the rate of 10 watts. Referring to the speed of meters, it was certain that low speeds were to be preferred, and that 480 revolutions per minute at full load were quite allowable. One important defect, which the Author had omitted to notice, was the internal friction of these instruments. In motor meters the work of the dynamo, or of the integrating apparatus, did not represent only the work absorbed by the brake, but further, the friction of the instrument. And, although one was struck by the very ingenious devices used to render this friction as slight as possible, it could not be supposed that this friction remained constant. The chief advantage of Mr. Brillié's meter was that the measuring apparatus was quite free from the effects of friction, being entirely independent of the motor. It was, in

Mr. Roux. short, only a relay, which could just as well command a motor of 100 HP. By this arrangement, the speed measured was not a function of the friction; more or less energy was spent in the motor according to it, but it was always ensured that equilibrium obtained between the force developed by the electro-dynamometer and that exercised upon the disk. If the friction increased, the speed of the motor tended to diminish the currents developed in the copper disk, and its active effort diminished; consequently the action of the coil of the electro-dynamometer would preponderate; it would turn to the right, and thus increase the power of the current passing through the motor, which power would increase until equilibrium was restored. The measurement was very accurate, and might be well compared to the action of a good steam-engine governor, which preserved a constant speed in that motor, whatever might be the variations of pressure, friction, or load.

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3 May, 1892.

GEORGE BERKLEY, President,
in the Chair.

It was announced that the following Associate Members had been transferred to the class of

Members.

Peter Chalmers Cowan, B.Sc.
Henry Herbert Gahan.
Francis Blayney Maclaran.
Walter Shellshear.

Also that the following Candidates had been admitted as

Students.

John Taylor Babtie.
William Henry Bickerton.
Thomas Brammall Cooper, B.Sc.
Sydney Couper.
Reginald Harratt Crompton.
Patrick Dunlop Donald, B.Sc.
Ernest Hubert Flower.
Alexander George Ionides, B.A.
Francis Alden Knott.
Gerald Gascoigne Lynde.
Charles Geoffrey Satterthwaite.
Robert Cherry Sikes, B.E.
Harry Morton Waynforth.
Samuel Whitworth.

The following Candidates were balloted for and duly elected as

Members.

John Butler Johnson.
Joseph John Mullaly.
Richard Wyndham Vaughan.

Associate Members.

William Alexander.
James Wood Bragg, B.A., Stud. Inst. C.E.
John Douglas Ormond Bridges.
Thomas Howard Chapman, Stud. Inst. C.E.
Alexander Cleghorn.
Sidney Ward Conyers.
John Poole Davis.
Clinton Coleridge Farr, B.Sc., Stud. Inst. C.E.
John Ferguson, Stud. Inst. C.E.
Alexander Orme Fraser.
David Hay.
Clinton James Wilson Holme.
William Dalton Ironside.
Edward William Lancaster.
Albert William Lawson, Stud. Inst. C.E.
Charles James Lomax.
David Lyell.
Robert John Dudley MacAllister.
Grieve Macrone.
John May.
Majoribanks Keppel North.
Edward Cooper Poole.
Fulton Robertson, B.Sc.
Andrew Shirlaw.
Frederick Charles Joseph Stowell.
Robert Boucher Tucker.
Charles Rufus Fairbanks Twining.
Herman George Wilson.

Associate.

George Handley Knibbs.

The discussion of the Paper by Mr. James Swinburne on "Electrical Measuring Instruments" occupied the whole of this meeting.

LIST OF INSTRUMENTS, &c.,

EXHIBITED AT THE MONTHLY RECEPTION, 26 April, 1892.

Exhibitors.	Objects.
Acme Electric Works	"Acme" ampere-meters (2).
	"Ayrton and Perry" magnifying-spring ammeter.
	"Ayrton and Perry" magnifying-spring ammeter and voltmeter combined (portable form).
	"Ayrton and Perry" twisted-strip voltmeter.
	"Teague" electricity-meters (2).
Professor W. E. Ayrton, F.R.S., Assoc. M. Inst. C.E.	First commutator permanent-magnet ammeter, 1880.
	First wattmeter in England, 1881.
	Ohmmeter, 1881.
	Second form of ohmmeter, 1882.
	First wheel-and-pinion ammeter, 1882.
	First gaining-clock supply-meter, 1882.
	Direct-reading ammeter and voltmeter, 1883.
	First magnifying-spring ammeter, 1883.
	Experimental hot-wire voltmeter, 1887.
	Experimental secohmmeters, 1887.
	First vertical magnifying-spring ammeters, 1888.
	First alternate-current magnifying-spring ammeter, 1888.
	"Ayrton and Mather" electrostatic voltmeters, 1890 (3).
O. Berend & Co.	"Hartmann and Braun" amperemeter.
	,, ,, electricity-meter.
	,, ,, inductometer.
	,, ,, hot-wire voltmeter.
	,, ,, pocket voltmeter.
	Central-station voltmeter.
Major P. Cardew, R.E.	"Cardew, Drake, and Gorham" leakage-indicator for high-tension mains.
Latimer Clark, Muirhead, & Co.	"Ayrton and Perry" ammeters (Types A and B).
	,, ,, voltmeter.
	,, ,, twisted-strip voltmeter.
	Vertical-face voltmeter.
	"Blackburn" portable testing-apparatus.
	"Clark" standard cells (2).
	Portable Wheatstone bridge.
Henry H. Cooper & Co.	"Brillié" meter.
Crompton & Co.	Current-indicators (4).
	Potentiometer.
	Voltmeters (2).
Day & Co.	"Central-station companion."

Exhibitors.	Objects.
Drake & Gorham	"Holden, Drake, and Gorham" dead-beat ammeter.
	"Holden, Drake, and Gorham" cell-tester.
	"Cardew" voltmeters (3).
Edison & Swan United Electric Light Company	"Cardew" engine-room voltmeters.
	"Fleming and Gimingham" voltmeter.
Elliott Brothers	Platinoid resistance-coils.
	Galvanometer (foreign service pattern).
	„ (sine and tangent).
	"Thomson" reflecting astatic galvanometer.
	Potentiometer.
	"Mengarini" registering voltmeter.
S. Z. de Ferranti	"Ferranti" meters (2).
Professor George Forbes, F.R.S., M. Inst. C.E.	"Coulomb" meter.
Fowler, Lancaster & Co.	"Ayrton and Perry" spiral-spring amperemeter.
	"Chamberlain and Hookham" electricity-meter.
	"Ferranti" meter.
	"Ayrton and Perry" horse-shoe voltmeter.
	"Crompton" voltmeter.
	"Desruelle" voltmeter.
	"Lancaster" voltmeter.
General Electric Company	"Aron" meters (5).
W. T. Goolden & Co.	"Evershed" ammeters (5).
	„ portable generator, with carcase.
	„ direct-reading ohmmeter, for insulation-testing, with "plug," pressure, and current-coils.
	"Cardew" voltmeter.
	"Evershed" voltmeters (3).
Killingworth Hedges, M. Inst. C.E.	"Lane Fox" meter (early form).
James J. Hicks	Cardew voltmeters (2).
Hodges & Todd	Ammeter.
	Voltmeter.
Johnson & Phillips	"Kapp" permeameter.
Keys' Electric Company	Ammeter.
	Galvanometer.
	Voltmeters (2).
Laing, Wharton & Down Construction Syndicate	Wattmeter.
Nalder Bros. & Co.	Ammeters (2).
	"Holmes" cut-out.
	„ leakage-testing board.
	Resistance-frame.
	Voltmeters (2).
Paterson & Cooper	Ammeters (3).
	Voltmeters (6).
Robert W. Paul	"Microfarad" condenser.
	Ayrton and Mather "D'Arsonval" galvanometer.
	Two forms of reflecting galvanometer, with scale.
	Resistance-box, with bridge (new form).

Exhibitors.	Objects.
Robert W. Paul	Standard resistance-coil.
	Keys and switches for testing.
Richard Frères	Self-recording ammeter.
	Electricity-meter.
	Direct-reading voltmeter.
	Self-recording voltmeter.
St. James's & Pall Mall Electric Light Company.	Section of trunk-main between Duke Street and Carnaby Street central stations, constructed and laid by Siemens Bros. & Co., August 1891.
Schäffer & Budenberg . .	Pocket counter for rotary motion.
	Tacheometers (3).
Siemens Bros. & Co. . . .	Ammeters (2).
	Electro-dynamometer.
	Torsion galvanometer.
	Portable testing-set.
	Voltmeters (2).
Swinburne & Co.	Central-station kilowattmeters (2).
	„ „ amperemeters (2).
	„ „ voltmeters (2).
	„ „ electrostatic voltmeters, for 2,000 volts (2).
	Non-inductive wattmeter, laboratory type.
Walsall Electrical Company.	Ammeter.
	Voltmeters (3).
Westinghouse Electric Co.	"Schallenberger" meter.
James White	"Deka" ampere-balance.
	"Kelvin" ampere-gauge.
	„ rheostat (improved).
	„ electrostatic voltmeter.
Woodhouse & Rawson . .	Combination plug and meter bridge
	Student's tripod galvanometer.
	"Pentane" lamp.
	Legal unit of resistance.
	"Cunynghame, Woodhouse, and Rawson" voltmeter.

10 May, 1892.
GEORGE BERKLEY, President,
in the Chair.

Mr. George Berkley, President, before the commencement of the ordinary business, regretted to announce the death of Lord Bramwell, who, as an honorary member, had for many years taken a deep interest in the welfare of the Institution. The distinction of honorary membership, which he had reason to know Lord Bramwell valued highly, was, in part at least, due to his labours in connection with the Royal Commission on Metropolitan Sewage Discharge—duties which he had fulfilled with great ability. The Council tendered to his brother, Sir Frederick Bramwell, one of their esteemed Past-Presidents, their sympathy on this sad occasion; and he ventured to suggest that the members should accept the expression of feeling which had been adopted by the Council in the foregoing terms.

(*Paper No. 2619.*)

"The Distribution and Measurement of Illumination."

By Alexander Pelham Trotter, B.A., Assoc. M. Inst. C.E.

SECTION I.—Introductory.

Light being an expenditure of energy, "candle-power" is an accurate term, since it is the measure of the rate of expenditure of energy; and the art of illumination is therefore, in a very definite sense, a matter which comes within the province of civil engineers, since it is the art of directing this power for the use and convenience of man. The study of light, its nature and laws, belongs to the science of optics, but we may look to optical treatises in vain for any useful information on the present subject. Illumination, if alluded to at all, is passed over in a few lines. There is at present no recognized unit by which it may be measured; the geometrical laws of its natural distribution are not commonly understood; and the specification of a required illumination of a street or of a railway-station would puzzle most contractors

When illumination is required, it ought to be possible to express intelligibly how much is wanted, and, a specification being given, it ought to be known how to execute it.

The photometry of lights, that is to say the measurement of candle-power, will only be alluded to briefly in the present Paper, for the purpose of sketching the development of photometers. There is very little to be said about this kind of photometry, unless from the point of view of testing the quality of gas, or from the point of view of the physicist, whose methods of measurement and analysis do not concern the present subject.

The English and French languages are remarkably rich in words connected with light, while such terms as illumination, brilliance, brightness, intensity and luminosity are generally employed by different writers to express different ideas, and are often used in a confused and vague way.

DEFINITION AND UNIT.

In the present Paper, the word light will be used to mean the luminous radiation emitted from a flame or incandescent surface, or reflected from a surface. It is measured as an intensity in any direction as candle-power. It is measured as a quantity by the product of the solid angle into the mean candle-power. The total quantity of light emitted by a luminous point in all directions is $4\ \pi$ times the mean candle-power. When light falls upon a surface, that surface is said to be illuminated. The illumination depends simply upon the quantity of light falling upon a given surface, and has nothing to do with the nature of that surface, just as rainfall is independent of the nature of the soil. Some of the light may be absorbed, and some may be transmitted. The brightness resulting from illumination has been called luminosity by Captain Abney.

Illumination consists of two factors, candle-power and distance. It is only necessary to allude briefly to existing standards of candle-power. These are in a very unsatisfactory condition, partly because the centimetre-gramme-second system cannot be extended to them. The English Parliamentary candle is not a more scientific or accurate standard than the barley-corn, of which three went to an inch. The unit which will sooner or later be adopted,[1] will probably aim at reproducing the mean value of the standard candle, of which six go to a pound, and which ought to consume 120 grains of sperm per hour. The relative merits of the Methven standard, which takes a sample patch of a gas-flame, or a pentane-lamp, need not be considered at present; they are fortunately of about the same magnitude as the French bougie decimale, one-tenth of the old carcel, and as the German vereinskerze, a paraffin-candle, 12 to a kilogram.

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[1] A joint Committee has been appointed to consider this question, by the Board of Trade, the London County Council, and the Gas Companies.

In the present Paper, the standard Parliamentary candle will be taken as the unit of candle-power.

A unit of illumination was proposed in France in 1882, and is self-explained by its name "carcel-metre." The carcel-metre has been shown by Mr. Preece[1] to be equal to a standard candle at 1·058 foot, and the name "lux" was proposed by him for the English equivalent, at the Paris Electrical Congress in 1889. It is owing to the general apathy with which the subject of this Paper has been regarded, rather than to a disinclination to twist British national measurements to fit the metric system, that neither this unit nor its name have come into general use. The bougie-metre, to which some French writers refer, is equal to one-tenth of a candle at a distance of 1·058 foot, or to one candle at $\sqrt{10} \times 1 \cdot 058 = 3 \cdot 35$ feet. The bougie-metre is a very feeble illumination, and is practically that which is to be found near a good street-lamp, having a 13-candle-power burner at a height of 12 feet from the ground. Convenient as the metric system is, its advantage for many engineering purposes is not yet convincing, and as the heights of lamp-posts and the width of streets are measured in feet, the candle-foot, that is, the illumination produced by one standard candle at a distance of 1 foot, will be taken in the present Paper as the unit of illumination. A candle-foot is 0·893 of a lux or carcel-metre, and a lux is 1·12 candle-foot.

The candle-foot is a very convenient and "comfortable" illumination.[2] It is, for most people, the best illumination for reading, and is to be found on most well-lighted dining-tables and billiard-tables. More than 2 candle-feet is seldom attained in artificial illumination. One candle at 1 foot is equivalent to four candles at 2 feet, nine candles at 3 feet, &c.; but to say off-hand how many candle-feet are produced by a sixteen-candle lamp, at a distance of 8 feet, is rather puzzling at first. The illumination is $\frac{16}{8^2} = 0 \cdot 25$ candle-foot.

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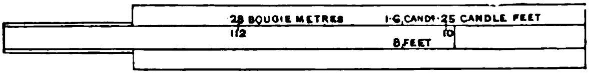
[1] Proceedings Royal Society, vol. xxxvi. p. 276.

[2] The illumination on the President's desk, at The Institution of Civil Engineers, is about 0·8 candle-foot.

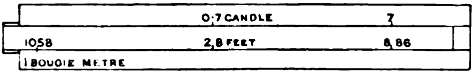
The illumination produced, in candle-feet or in bougie-metres, by any given candle-power at any given distance, may be found on a slide-rule thus:—

Fig. 1.



The value of any illumination in bougie-metres, for the sake of comparison with French work, may be found by the formula,—n candles at $1 \cdot 058 \times \sqrt{n}$ feet. Thus 0·7 candle-power at 2·8 feet, or seven-candle-power at 8·86 feet gives an illumination of 1 bougie-metre. This may be easily carried out on a slide-rule, thus:—

Fig. 2.



The conversion Tables given in the Appendix may be useful, as the square root and decimal places are rather puzzling, since the unit is so unfamiliar to most engineers that the decimal place cannot be guessed at.

The candle-foot, as already defined, assumes that the illuminated surface directly faces the source of light. If the surface is inclined to the direction of the rays of light, the illumination will diminish in proportion as the projected area of any part of the surface diminishes, when viewed from the source of light. The visible surface varies from unity, as seen full; to nothing, when seen on edge. The decrease varies, in fact, with the cosine of the angle of incidence. So little has the question of illumination been studied, that there is some ambiguity as to what is meant by the angle of incidence. It is a well-established convention among writers on optics, that the inclination between a ray and the perpendicular to a surface shall be called the angle of incidence. This angle will be frequently alluded to in this Paper, and it will be designated, where necessary, by θ. A ray, proceeding horizontally, will therefore be of 90° incidence; and a ray falling on the point immediately below a lamp, will be of 0° incidence on the horizontal plane beneath it.

DISTRIBUTION OF ILLUMINATION.

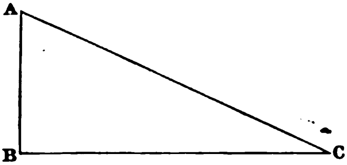
The nature of the illumination of a horizontal plane by a light radiating uniformly in all directions, is the most simple, and at the same time the most useful and common problem for outdoor work. The candle-power of the light may be assumed to be constant, and need not enter into the matter. It will be taken as unity. The height of the lamp above the ground is also constant, and may be taken as unity. The illumination at any point on the plane varies inversely as the square of the distance from the light; that is, inversely as the square of the slant-height of the lamp. It also varies as the cosine of the angle of incidence. In *Fig. 3* it will be seen that the height A B of the lamp being unity, the cosine of the angle of incidence B A C is measured by the ratio of the vertical height A B to the slant-height A C. The illumination will therefore be as the cube of the cosine of the incidence.

To obtain the illumination for special cases, it is sometimes convenient to use the simple trigonometrical ratios without reference to the angle of incidence. Thus the illumination at the point C may be reckoned as inversely proportional to the cube of the slant-height A C, and proportional to the height A B, and to the candle-power of the light.

$$i = \frac{AB \times \text{c.p.}}{AC^3},$$

where i is the illumination in candle-feet, c.p. the candle-power, and A B and A C distances measured in feet. Professor Henry Robinson, in a Paper read before the Association of Municipal and County Engineers,[1] suggested as an approximation for determining the minimum illumination, that the simple horizontal distance, instead of the slant-distance, should be taken. This implies that the illumination varies as the cube of the cotangent instead of the cosine. This approximation may suffice for very large angles, since both the cosine and the cotangent of 90° are 0, but the error becomes considerable even at 70°, for it is then 20 per cent. too great, while for small angles the cosine approaches unity, and the cotangent (being unity at 45°), approaches infinity.

Fig. 3.



The full curve in *Fig. 4* represents the illumination at any point on the horizontal plane, by the height of the ordinate at that point, the maximum being unity. The value of the cubed cosine being of great importance in all such cases, and being somewhat troublesome to calculate, Tables III and IV in the Appendix, together with the tangents of the angles of incidence, are given for convenience in rectangular plotting, as in *Fig. 4*.

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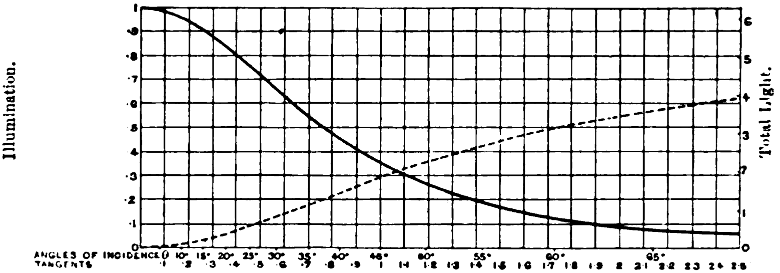
[1] Proceedings, vol. xvii. p. 237.

It must be remembered that, while the curve in *Fig. 4* shows very distinctly the gradual change in the illumination and allows very small differences to be appreciated, small changes cannot be estimated or even detected by the eye. Weber has shown that the intensity of visual sensation is not directly proportional to the luminous stimulus.[1] Illuminations, or indeed any other sensations, cannot be quantitatively compared, but equality can only be estimated, and that very roughly, compared with other measurements. An unpractised eye can with difficulty detect a difference of 8 per cent., as, for example, when two equal lights are placed at the ends of a 100-inch photometer bar, and the disk is displaced 1 inch from the middle. A little practice will enable 4 per cent. to be estimated, and figures pretending to an accuracy greater than 2 or 3 per cent. cannot, as a rule, be accepted, unless as the mean of a number of readings. But gradual changes of illumination, imperceptible though they may be, have an actual existence; and, though the Tables which accompany this Paper contain four-figure values, they need not be regarded as aiming at extreme accuracy, but are provided as a basis for other calculations. Illumination on a horizontal plane decreases so rapidly with the distance, that at an angle of incidence of about 37° it falls off to one-half, at about 40° to one-third, and at 62° to one-tenth of the maximum.

Fig. 4.



—— $\cos^3\theta$ curve. ----- $\frac{\pi}{2}(1-\cos\theta)$ curve.

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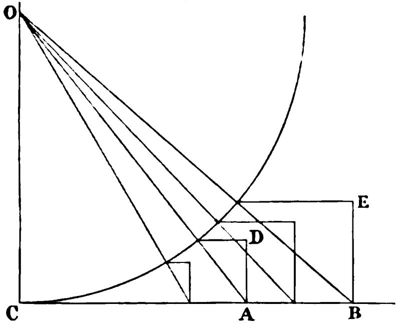
[1] Weber's law has been expressed thus: "The smallest change in the magnitude of a stimulus which we can appreciate through a change in our sensation, always bears the same proportion to the whole magnitude of the stimulus. . . . This law holds good within certain limits only; it fails when the stimulus is either above or below a certain range of intensity." Michael Foster, "Text Book of Physiology." 5th edition. Part IV. p. 1211.

By a rather troublesome application of integral calculus,[1] it may be shown that the cubic contents of a solid of revolution swept out by the revolution of the cosine-curve about its axis is 2π; but by simple geometry it is obvious that the total amount of light emitted in all directions from a radiant point is measured by the surface of the surrounding sphere of unit radius; this is equal to 4π. The amount falling on an indefinitely extended plane is therefore one-half of this, or 2π. It follows that if only a portion of the whole light be considered, it may be measured as the amount of the surface of the surrounding sphere; that is to say (the radius being unity) by the solid angle, subtended by that part of the sphere, or by any other surface, at the radiant point. This solid angle may be expressed trigonometrically, but it may be treated much more intelligibly by Archimedes' theorem,—that a sphere and its circumscribing cylinder being cut by planes perpendicular to the axis of the cylinder, the intercepted portions of the surface are equal in area. A quadrant of the sphere of unit radius being drawn (*Fig. 5*), let O A and O B be rays falling on the plane at the points A and B. Erect perpendiculars from these points, and draw horizontal lines through the points at which they cut the quadrant, cutting the perpendiculars at D and E. The lengths A D and B E represent the total light falling on the cones swept out by O A and O B. The dotted line in *Fig. 4* is the curve obtained by this construction; the scale on the right gives the solid contents, or total light. At 60°, that is to say, a circle subtending 120°, one-half of the total light is received, and the curve continually approaches the value 2π.

Fig. 5.



CONSTRUCTION FOR CURVE OF TOTAL LIGHT.

A useful application of the knowledge of the total light received on a surface may be made in the measurement of the reflecting-power of a dead-white surface. There is no difficulty in testing the reflecting-power of a plane mirror or metallic reflector, since the reflected ray travels in a definite direction, and may be received on a photometer. But the light reflected from a dead-white surface is diffused over a whole hemisphere, with a power very nearly proportional to the cosine of the angle of reflection, the deviation from this proportionality being due to imperfect smoothness or to partial polish. Because 1 square foot of white paper does not seem to be so useful a reflector as 1 square foot of looking-glass, it has been erroneously assumed that its reflecting-power is small. The estimation of the whole light reflected by measuring the light sent in one direction, appears at first to involve a troublesome application of integral calculus, but this is not the case. It is only necessary to take a disk of the reflecting material, and to place it behind a candle, so that its diameter subtends 120° to the centre of the flame, to ensure that it receives exactly one-quarter of the whole light emitted, or one-half of that which is emitted in one hemisphere. If, after making allowance for the greater distance of the disk from the photometer, the candle-power is increased by 40 per cent., the reflecting-power of the material is 80 per cent. It is possible to intercept practically one-half of the light, by placing a large reflector very close to the flame. Measurements with good paper, plaster of Paris, and even white-wash, show that their reflecting-power is equal to that of ordinary looking-glass, viz., about 85 per cent.

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[1] See appendix to a Paper by the Author on "A Dioptric System of Uniform Distribution of Light," Minutes of Proceedings Inst. C.E., vol. lxxviii. p. 335.

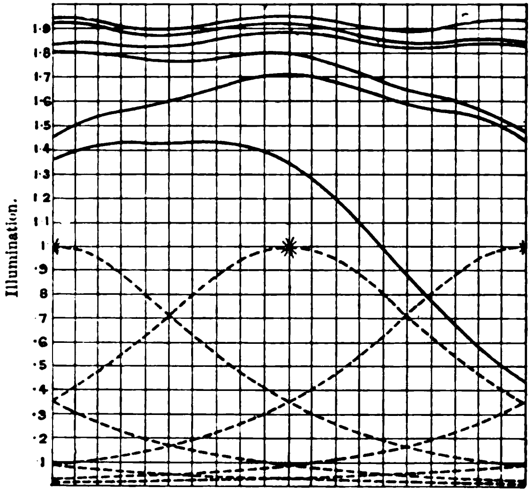
White porcelain and enamelled iron are not so good, but, being glazed, they send a little light in a definite direction, and this makes a strict comparison difficult. The usefulness of a white reflector in practice depends almost entirely on the solid angle which it subtends to the light, and not, as is sometimes imagined, to its absolute dimensions.

EXAMPLES OF DISTRIBUTION.

By the practical application of the cosine law, the illumination which will be produced by any given arrangement of lights may be determined. The excellent illumination of Hyde Park Corner by gas-lamps has been brought about by merely adding to the number of lamps until the illumination was sufficient. When it was desired to illuminate the City by electric light, various experiments were made with temporary posts of different height, to try the "effect." The principal object of this Paper is to attempt to enable engineers to predetermine, specify for, and provide, a definite illumination.

The curve given in *Fig. 4*, and the table of values of cosine^3 θ (Appendix, Table III), enable the curves for the combined effect of a number of lamps to be determined by the simple addition of ordinates. *Figs. 6, 7, 8*, and *9* give the component and resultant curves for four different arrangements. The first, *Fig. 6*, consists of a row of lamps at a distance apart equal to their height, from the ground. The dotted lines show the cosine-curves, and the illumination produced by the neighbouring lamps is shown by the full lines. The first full line shows the resultant illumination of two lamps, and the next one above, a symmetrical portion being given, represents the illumination due to three lamps. The other lines similarly show the additional effect of the more remote lamps. The illumination at the maximum is 1 + twice the cubes of the cosines of the angles whose tangents are 1, 2, 3, 4, &c., and is 1·978 when there are four lamps on each side. The minimum illumination is equal to twice the cube of the cosines of the angles whose tangents are 0·5, 1·5, 2·5, 3·5, &c., and is equal to 1·932 for five lamps. The resultant curve is practically symmetrical about a horizontal line, and the mean illumination may be taken as the arithmetical mean of these values. It is hardly necessary to point out that the eye could scarcely detect any variation in the illumination thus produced, the difference being only $2\frac{1}{4}$ per cent.

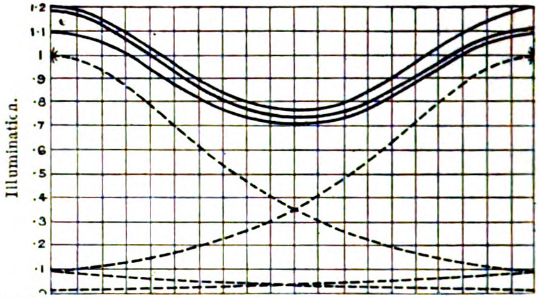
Fig. 6.



Resultant Illumination due to Lights at a Distance apart Equal to their Height.

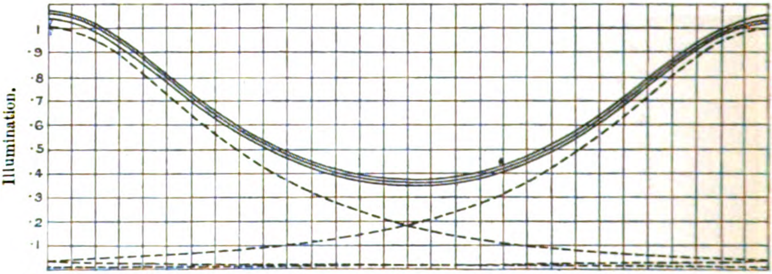
The next arrangement, *Fig. 7*, is that of lamps placed at a distance apart equal to twice their height. The full lines show the effect of the neighbouring lamps. The maximum is 1·219, being 1 + twice the cubes of the cosines of angles whose tangents are

Fig. 7.



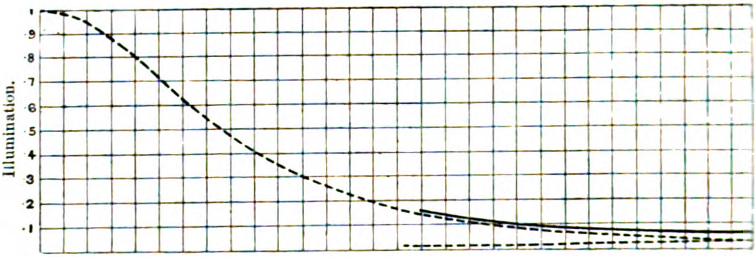
RESULTANT ILLUMINATION DUE TO LIGHTS AT A DISTANCE APART EQUAL TO TWICE THEIR HEIGHT.

Fig. 8.



RESULTANT ILLUMINATION DUE TO LIGHTS AT A DISTANCE APART EQUAL TO THREE TIMES THEIR HEIGHT.

Fig. 9.

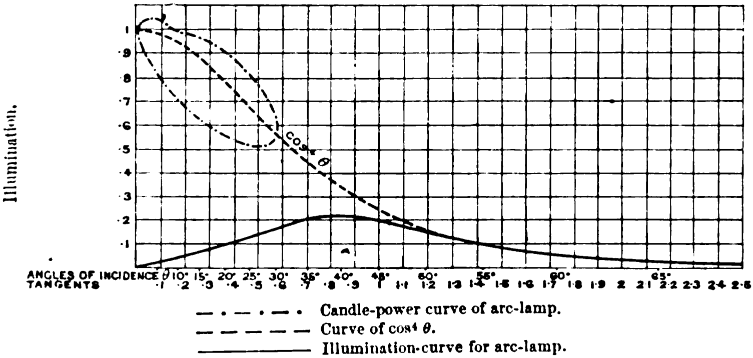


RESULTANT ILLUMINATION DUE TO LIGHTS AT A DISTANCE APART EQUAL TO SIX TIMES THEIR HEIGHT.

2, 4, 6, 8; and the minimum is 0·7836, being twice the cubes of the cosines of the angles whose tangents are 1, 3, 5, 7. The minimum is 35·8 per cent. less than the maximum. The mean is practically unity. In the next arrangement, *Fig. 8*, the distance is three times the height. The maximum is 1·073, and the minimum is 0·362. The minimum is 63·8 per cent. less than the maximum. This variation is, of course, very marked, but is not nearly so apparent to the eye as is indicated by the curves. The last example, *Fig. 9*, is a common arrangement in street-lighting, the distance apart being six times the height of the lamps from the ground. The maximum is 1·01, and the minimum is 0·0632, the additional effect of only one lamp on each side has been considered. The variation is about 93·7 per cent. In the last two cases it is useless to consider the mean illumination.

Two practical modifications must be considered with regard to these results, one being the reflection by neighbouring houses, which assists the illumination of the region midway between the lamps, and the other being the shadow which is always to be found below a lamp, whether thrown by the gas-burners and the bottom framing of the lantern, or by the lower carbon of an arc-lamp. The first of these modifications, though specially looked for by the Author in street-lighting measurements, was hardly appreciable except in cases of very feeble illumination. The second is a very marked feature with all street-lamps except those which are provided with good reflectors.

Fig. 10.



The light of ordinary gas-burners is not quite uniform in all horizontal directions, since the flame is not perfectly transparent, and there is some variation of candle-power at different angles with the horizon,[1] but these are trifling compared with the natural variations which have been described. The light of arc-lamps is emitted in a very well-defined manner, and does not differ materially in different makes of lamps, provided that the ordinary pair of carbons are used with a continuous current. *Fig. 10* gives a curve[1] showing the variation in candle-power, and the resultant illumination produced. With angles of incidence from 0° to about 55°, the light is obstructed by the lower carbon, which determines the candle-power. Beyond 55° the light follows a regular law, but not that of the cosine-cubed, for the light is not emitted from a mass of flame but from a horizontal disk or crater. The projected area of this crater, as seen from any direction, varies as the cosine of the angle. The cosine being introduced for the fourth time, the illumination varies as the fourth power of the cosine. The curve of $\cos^4 \theta$ is given in *Fig. 10.* The total light is π, and a right-angled cone contains half the whole light.

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[1] Radial measurements of gas-burners are given in "Practical Photometry," by W. J. Dibdin.

STREET-LIGHTING.

Electric glow-lamps have rarely been used with success for street-lighting up to the present: but too much has been expected from them. Street-lighting differs from almost all other lighting in that the actual illumination produced on the ground is not by any means the only important result; but since this illumination is so marked a feature of a well-lit street, it is often assumed to be the sole object of street-lighting. A very important function of street-lamps is that of beacons to mark out the road. The gas-lit buoys which mark out channels, give no appreciable illumination in the proper sense of the word, and the sense in which it is used in the present Paper, but they, none the less, serve a most important purpose. Ordinary 5-feet gas-burners in a wide and important street such as Piccadilly, and those in suburban roads, are of little use other than as guides.

Illumination begins to be useful when it is comparable with moonlight. Out of a number of measurements made by the Author at and near full-moon, none have ever reached a higher value than about one-thirty-sixth of a candle-foot; that is, a candle at 6 feet. A bright moon in London, standing high in the sky, is generally between one-sixtieth and one-hundredth of a candle-foot, that is, a candle at 8 to 10 feet. These illuminations were taken on a screen turned full to the moon, and do not include the diffused light from the surrounding sky, which is often considerable, and brings the whole illumination up to one-thirtieth of a candle-foot. The moon is not often alluded to in Papers before this Institution, but that it occupies a somewhat important place in engineering, is proved by the custom of dispensing with electric light in many towns in the United States on moonlight nights, and the fact that American Electric Journals give monthly tables of the moon. As much coal is probably saved in the United States in this manner, as might be saved by the use of steam-engines and dynamos of high efficiency.

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[1] Derived by Mr. Wybauw from measurements of twenty-six different arc-lamps by Professor Rousseau at the Antwerp Exhibition, 1885.

Moonlight is a useful standard of illumination, but it must be remembered that the perfect uniformity gives it a rather fictitious value, and it is not until an attempt is made to read, say, the time on a watch, that its real feebleness is apparent. A unit of illumination, having perhaps quite as close a connection with the C. G. S. system as has the Parliamentary candle, is that illumination at which it is possible to read Bradshaw's Guide. Moonlight in this country does not come up to this standard.

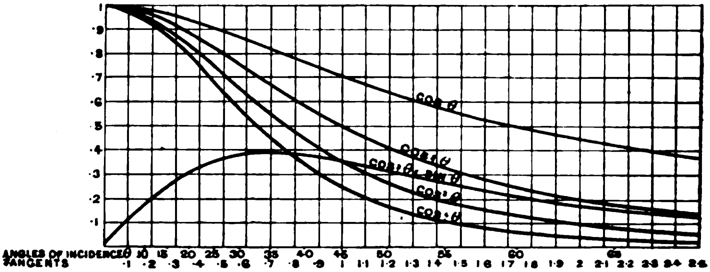
The varying height of the moon in the sky, and the different illumination which is thereby cast on the ground and on the walls of houses, calls attention to the fact that the illumination on the ground must not be the only consideration of outdoor lighting. For the lighting of docks, wharves, railway goods-yards and other open spaces, the horizontal illumination demands most attention. But it may be suggested that for street-work and the lighting of large interiors, such as railway-stations, the illumination of side-walls is quite as important, and that if any one wishes to consult his watch he will not hold it horizontally, but with the face turned full towards the light. It appears best to aim at a fair illumination of the ground, this being the most difficult. If there are houses near the lamps, so much the better for the general effect, but the lamps should not be spaced further apart for this reason.

GENERAL CASES OF DISTRIBUTION.

The illumination on a surface turned full to the light varies inversely as the square of the distance, and, according to the convention assumed in this Paper, as the square of the cosine of the inclination of the ray with the vertical. The curve of illumination of this character is shown in *Fig. 11.* The illumination of a vertical plane, the height of which is small compared with the height of the lamp—for example, the side of a truck in a goods-yard lighted by high lamps, is proportional to the product of the sine of the angle into the square of the cosine. The curve of this illumination is given in *Fig. 11.* It will be noticed that it is zero below the lamp, and is equal to the illumination on a horizontal plane at 45°, and continually approaches the curve of the squared cosine. The curve of cosines from which all these functions are derived, is also given in *Fig. 11*, from which the illumination on any surface, and at any reasonable distance from the lamp, can be found. Table V in the Appendix gives the values of θ, $\cos\theta$, $\cos^2\theta$, $\cos^3\theta$, and $\cos^4\theta$, from which *Fig. 11* was plotted. The illumination on the wall of a house facing a lamp, and at a distance measured by the angle of incidence of a ray striking its foot, follows the square of the cosine on that part which is on a level with the light, and falls off to the product of the sine into the square of the cosine at the foot of the wall.

Precisely the same law is followed in the variation of the illumination at a given point, when a lamp in the neighbourhood is placed at different heights in a perpendicular line. This case seems to have been misunderstood by several writers. The curve in *Fig. 12* represents the illumination produced at the point A by a source of light placed at different heights in the vertical line BC. This curve differs from the preceding ones in this Paper, since the illumination is here measured along the horizontal scale instead of the vertical. The vertical scale in this figure represents the variable height of the source of light; when the light is situated at the point D, the illumination at A is a maximum, and it may be shown that BA = BD × $\sqrt{2}$, and that the angle of incidence BDA is 54° 44′. It will be observed that a small change in the height BD may be made without appreciably altering the illumination at A. If the height be decreased, the illumination at A will fall off owing to the large angle of incidence. If the height be increased, the illumination will be diminished owing to the increased distance.

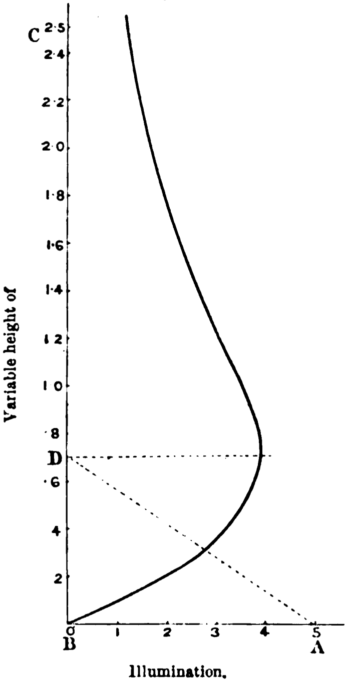
Fig. 11.



CURVES OF $\cos\theta$, $\cos^2\theta$, $\cos^3\theta$, $\cos^4\theta$, AND $\cos^2\theta\sin\theta$.

But it cannot be deduced from this that, for ordinary illumination of open spaces, there is any special virtue in the angle of incidence, or that a circle having a radius $\sqrt{2}$, the heights of the lamps being unity, is more "efficiently" lit than any other. The illumination at the circumference of such a circle is very nearly 0·2 of the maximum, which would be found immediately below the lamp, if it emitted light uniformly in all directions. The total light falling within the circle is 0·427 of the whole light falling on the horizontal plane below the lamp. The distribution produced by several lamps in a row, each being supposed to command such a circle, would closely resemble that represented in *Fig. 8*; the usefulness of this arrangement is really limited to the particular case represented in ***Fig. 12***, viz., the maximum illumination of the point A by a lamp situated at any point in the line C B.

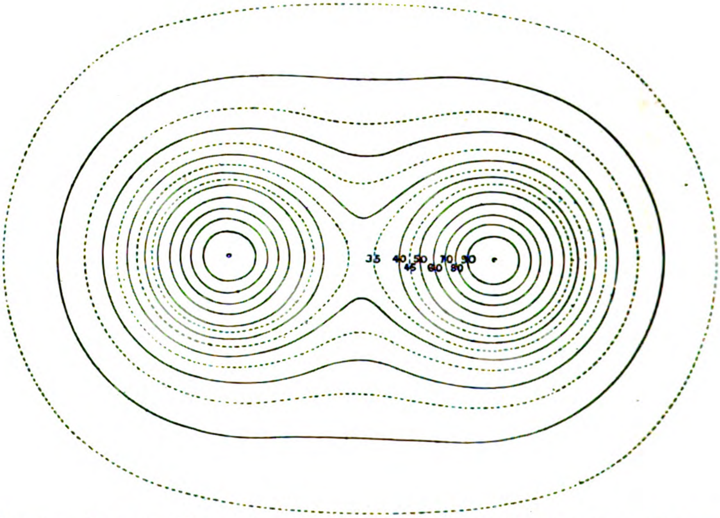
Fig. 12.



Distribution over a Plane.

The foregoing considerations relate only to the distribution of illumination along a straight line, and the typical curves in ***Figs. 6, 7, 8,*** and ***9*** show the result of different spacings only in the line of the lamps. With the exception of such rare cases as Hyde Park Corner, or the illumination of a very large hall, the arrangement of the lamps almost always consists of rows of lamps set alternately on each side of a street, or a single row down the middle, as on many railway-platforms, and in Tottenham Court Road and Euston Road. With the view of learning what might be expected in practical lighting, the contour-lines of equal illumination given in ***Figs. 13, 14, 16,*** and ***18*** were calculated and drawn. ***Fig. 13*** represents the contour-lines of equal illumination given by two lamps at a distance apart equal to three times their height. If these contour-lines be considered to represent a solid figure, then *Fig. 8* represents a vertical section through such a figure in the line A B, with this difference: that *Fig. 13* represents the result of two lamps only, while *Fig. 8* represents the space between the two middle lamps of a row of four. Full lines are drawn for the contours of 90, 80, 70, &c., and dotted lines for 45 and 35, the maximum illumination below the lamp being 100. The contour-lines for lamps at a greater distance apart are very similar to those shown in *Fig. 13*, and always consist of more or less circular curves, surrounded by hour-glass shaped curves which pass into more or less elliptical curves. The resultant contour-lines for three lamps placed at the corners of an equilateral triangle, the side of which is 1·5 of the height of the lamp above the ground, are given in *Fig. 14*. Treating this as a solid figure, *Fig. 15*, an illumination-curve like *Figs. 6 to 9*, may be considered as a section through the line A B of *Fig. 14*.

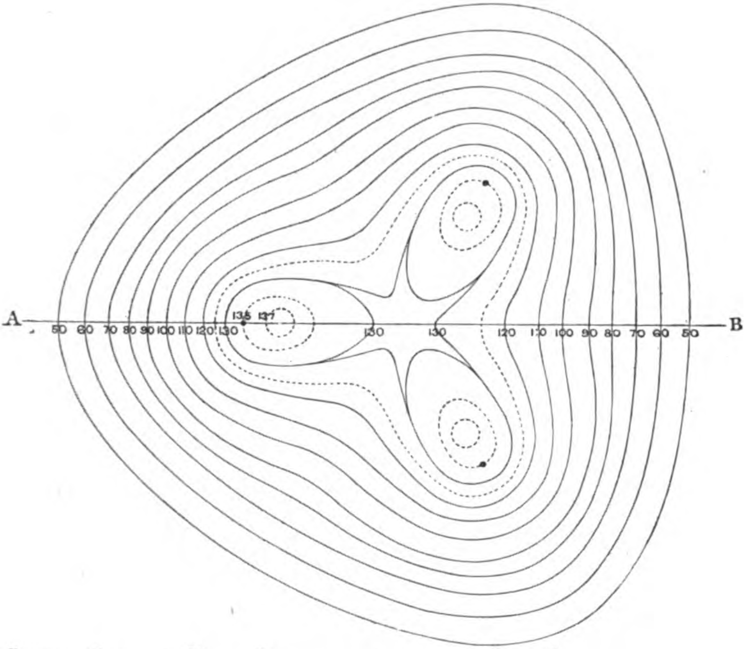
Fig. 13.



Contour-Lines of Equal Illumination due to Two Lights at a distance apart equal to Three Times their Height.

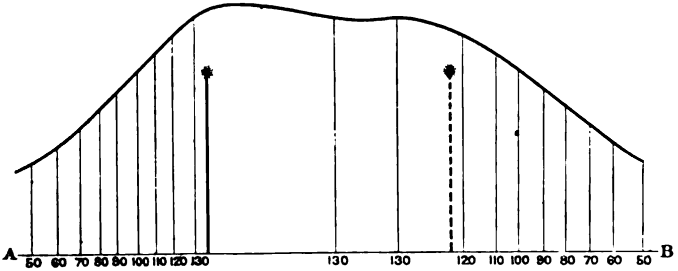
It is to be noticed that the points of maxima are not under the lamps; and that within the triangle, the illumination does not vary more than 10 per cent. The contour-lines for three lamps more widely spaced are of the same character, but become less interesting, as the more or less circular contours round the lamps become more important; and, in most cases of street-lighting, the other curves are negligible, since they would refer to differences of illumination which are far too small to be of any practical importance.

Fig. 14.


A
50 60 70 80 90 100 110 120 130
135 137
130
130
120 110 100 90 80 70 60 50
B

CONTOUR-LINES OF EQUAL ILLUMINATION DUE TO THREE LAMPS AT DISTANCES APART EQUAL TO ONE-AND-A-HALF TIMES THEIR HEIGHT.

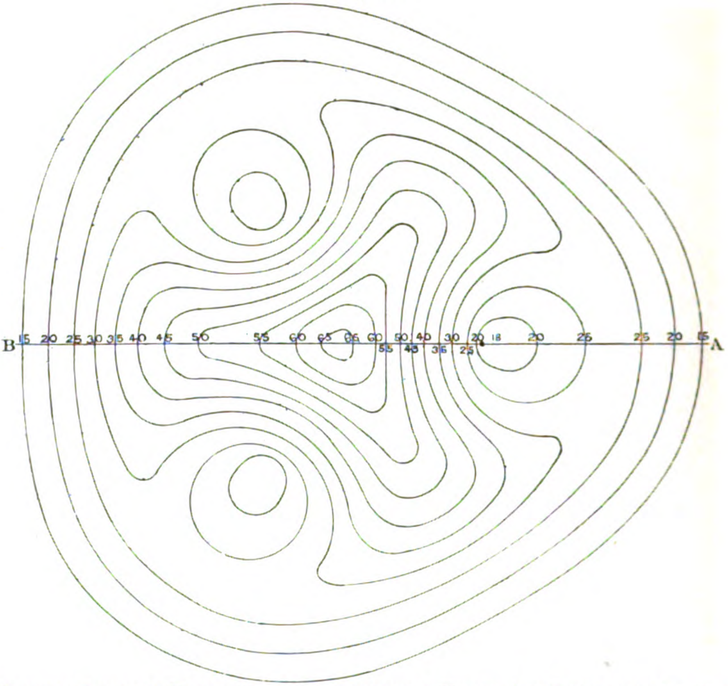
Fig. 15.



CURVE OF ILLUMINATION DUE TO THREE LAMPS AT DISTANCES APART EQUAL TO ONE-AND-A-HALF TIMES THEIR HEIGHT, BEING A SECTION OF *Fig. 14* THROUGH THE LINE A B.

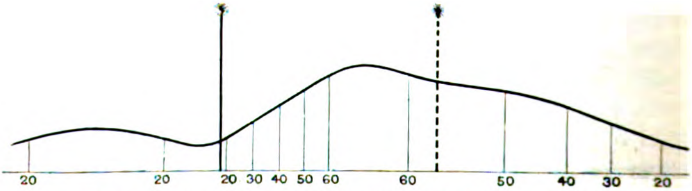
With arc-lamps the contour-lines present a very different character, owing to the peculiar distribution of the light. The contour-lines shown in *Figs. 16* and *18* have been constructed on

Fig. 16.


B
15
20
25
30
35
40
45
50
55
60
65
66
60
55
50
45
40
35
30
25
20
18
20
25
25
20
15
A

Contour-Lines of Equal Illumination due to Three Arc-Lamps at distances apart equal to One-and-a-Half Times their Height.

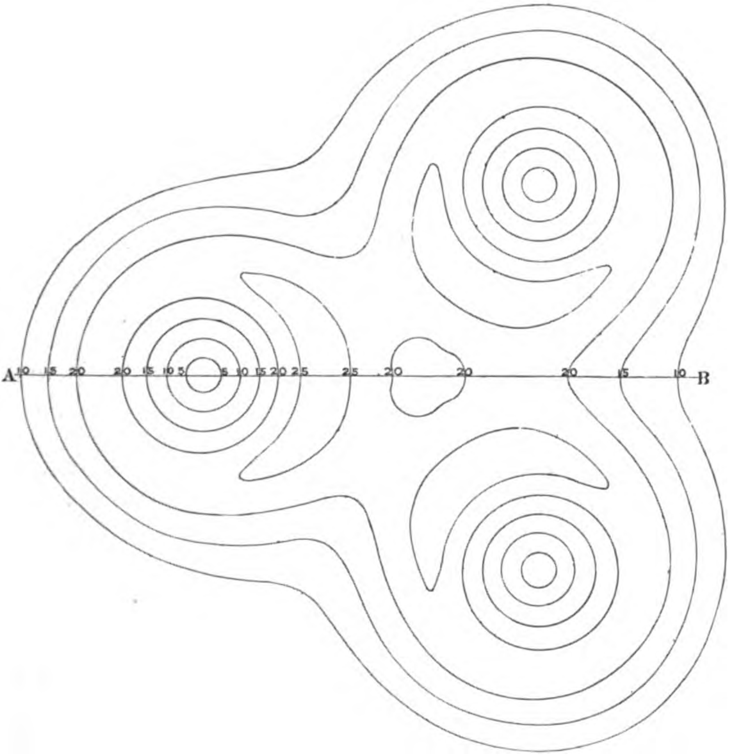
Fig. 17.



Illumination-Curve Along the Line A B of *Fig. 16.*

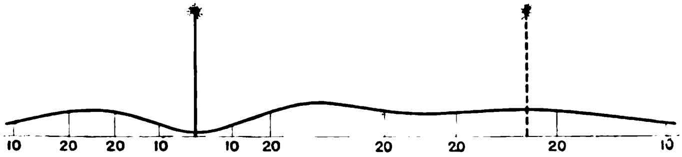
the assumption that the light is distributed according to the curve obtained by Mr. Wybauw, which is given in *Fig. 10.* The lines in *Fig. 16* represent the distribution of illumination due to three arc-lamps at distances apart equal to 1·5 of their height. *Fig. 17* represents a section through A B in *Fig. 16*. *Fig. 18* shows the

Fig. 18.



Contour-Lines of Equal Illumination due to Three Arc-Lamps at distances apart equal to Three Times their Height.

Fig. 19.



Illumination-Curve along line A B of *Fig. 18.*

contour-lines for three arc-lamps placed at distances apart equal to three times their height, and *Fig. 19* represents a section through

A B, *Fig. 18.* The values given for the illumination at each contour are arbitrary, but do not differ much from the values given in *Fig. 10.* These curves (*Figs. 14*, *16*, and *18*) have been constructed by a modification of a method described by M. F. Loppe, (*L'Électricien*, 1890, vol. xiv. p. 957), but the Author is not aware that any such contour-lines have been published. The sections were deduced from the contours.

Five or six visits were made to Queen Victoria Street, the earlier ones to test the range of the scale, and the mechanical details of the photometer, and two for careful measurements of the illumination of the street. Besides numerous measurements of maxima and minima, readings were taken at about every 10 feet along the zig-zag line joining three lamps. Similar measurements were made in Cornhill, Tottenham Court Road, Euston Road, Whitehall, and Great George Street. The results are given in the third section of the present Paper.

These measurements may be expressed graphically in three different ways. (1) By illumination-curves, like *Figs. 6–9*; (2) by contour-lines, like *Figs. 13*, *14*, *16*, and *18*; or (3) by curves which express all the important points or characteristics of any example of illumination. For these, the Author suggests the name characteristic curves.

ILLUMINATION-CURVES.

The Author is still rather doubtful as to the best ratio of the vertical scale to the horizontal scale for the illumination-curves. The convention assumed in the earlier part of this Paper, that the height of the lamp and the maximum illumination should both be taken as unity, ceases to be useful when the maximum has an arbitrary or accidental value, as in arc-lighting. At angles of incidence greater than 55°, it has been already shown that the illumination from an arc-lamp on a horizontal plane practically varies as the fourth power of the cosine. It is found that the maximum illumination is in practice at about 45°, and, from Table V in the Appendix, it is seen that the fourth power of the cosine of 45° is 0·25. If, then, the height of the lamp be set off on the same scale of feet as the horizontal measurements, and if it be assumed that the maximum illumination measured on a vertical scale be represented by a height equal to 0·25 of the height of the lamp, the illumination-curve will correspond, as nearly as is practicable, with the ideal curve given in *Fig. 10.* The illumination-curve in

Fig. 31, which will be described later, is arranged thus. On the other hand, the shapes of the curves can be more readily compared, and space may be saved, by making the ordinate representing the maximum illumination equal to the height of the lamp; while the most convenient method is to fit the scale of illumination to any arbitrary number of squares on squared paper, as in *Figs. 29*, *30*, *32*, *33*, *35*, &c.

CONTOUR-LINES.

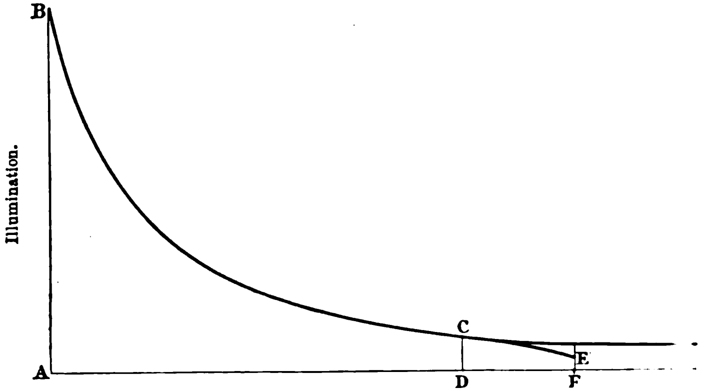
While the illumination-curves give a good idea of the distribution along a given line, they do not express the distribution over the whole area. The contour-lines in most street-work resemble *Fig. 13* rather than *Fig. 14*; but it will be seen in *Fig. 35*, which will be described later, that they practically consist of circles with a fairly uniform space between them. To give an idea of the distribution, the difference between each line should of course be constant. In the present examples they are drawn at every tenth or twentieth of a candle-foot.

With such wide spacing of the lamps, the hour-glass-shaped lines which run in at the minima are beyond the limits of accuracy of the present work, and would be influenced by insignificant flickering, irregularity of glazing of the lamp, and unevenness of the street. It must be confessed that when a fair number of contour-lines are given, and all of them are practically circular, the lighting of the street is "spotty."

CHARACTERISTIC CURVES.

A characteristic curve of illumination is a diagram which resembles a steam-indicator diagram in several respects, since the co-ordinates are the measures of an intensity and of an extension respectively, and the area is the measure of a power. The ordinates show the illumination, and the abscissæ the areas. The maximum and minimum illuminations may be seen at a glance, and the shape of the curve shows the quality or regularity of distribution. The departure of the upper line from the horizontal shows the want of uniformity of illumination. The area illuminated to any given degree may be easily found, just as an indicator-diagram shows that portion of the stroke during which the steam-pressure exceeds any given amount. The area of the diagram is a measure of the total light, and is really a measure of power in an optical form. Taking the simplest possible case, viz., a single lamp emitting light uniformly in all directions, the illumination-curve being expressed by the full line in *Fig. 4*, a circle of any given radius being selected, the character of the illumination may be expressed by plotting areas as abscissæ, and the candle-foot to be found on those areas as ordinates. Taking the minimum illumination as 0·1, the radius may be found from Table III, as 1·907, the height of the lamp and the maximum illumination being unity. The area of this circle is 11·4. The curve A B C D, *Fig. 20*, is calculated from Table III, the horizontal measurements being areas. This curve differs from the cosine-cubed curve in *Fig. 4* only in the horizontal scale, the former being the square of the latter, but reduced to a convenient length. The early part of the curve becomes as it were shrivelled up, and the flat top seen in *Fig. 4* is imperceptible.

Fig. 20.



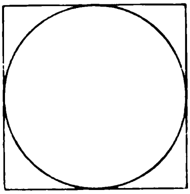
Characteristic Curve for a Circular, and for a Square, Area.

If, instead of a circular area, a square one be chosen, the extremity of the characteristic curve becomes modified. Let a square be circumscribed round the circular area, as in *Fig. 21*. The parts of the square beyond the circle diminish in illumination, but diminish more rapidly in area as their distance from the centre increases. The limiting illumination is found to be 0·04, and the remainder of the curve has been calculated, and is represented by C E in *Fig. 20.*

Since the characteristic curve may be regarded as a cosine-cubed curve, with a transformed scale of abscissæ, the characteristics of those types of distribution shown in *Figs. 6, 7, 8*, and *9*, may be found. When a characteristic curve is drawn to represent the distribution of illumination of more than one light, the maximum area may be reduced to one hundred; and areas are then represented on a decimally divided horizontal scale, from which percentages may be read off. The characteristic curves given in *Fig. 22* are derived from the curves in *Figs. 6, 7, 8*, and *9*, both the maximum illumination and the maximum area being reduced to one hundred.

These characteristics do not strictly represent the distribution of illumination over a large area illuminated by lamps in rows, since there are several different ways in which such lamps may be arranged, viz., quadrilaterally, as at the corners of squares on a chess-board; quincuncially, as at the centres of squares of one colour on a chess-board; or hexagonally, as the cells of a honeycomb. The variations of illumination represented in *Fig. 22* are simply those of the resultant curves in *Figs. 6* to *9*, and the areas are supposed to be circular.

Fig. 21.



The characteristic of $d = 3h$ (that is, distance of lamps equals three times their height), does not present any remarkable features, and as this is practically the same as the illumination produced by a light commanding a circle whose radius is $\sqrt{2}$, the height of the lamp being unity, the peculiar efficiency of this arrangement, which has been alleged by some writers, is not apparent.

It has been suggested by Mr. W. H. Y. Webber,[1] who has commenced a series of articles since the greater part of the present Paper was written, that the practical measure of the efficiency of lighting is given by the difference between the brightest and the dimmest parts of the illuminated area. This difference is represented by the difference between the curves of maxima and minima in *Fig. 23.* The way in which this difference increases with the wider spacing of the lights is worth noticing, but it conveys no information as to the area illuminated to different degrees.

With the calculated characteristic curves as guides, the characteristics of the examples of street-work may be approximately

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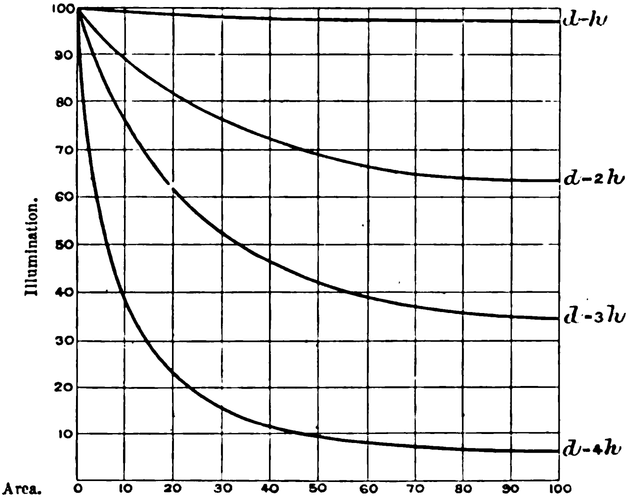
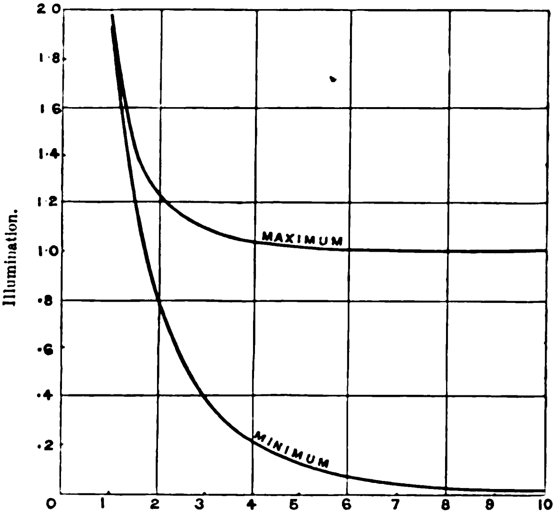
[1] Journal of Gas Lighting, vol. lix. p. 197. Feb. 2, 1892.

Fig. 22.



Characteristic Curves for Lamps, at a distance apart equal to Once, Twice, Three Times, and Six Times their Height.

Fig. 23.



Distances apart, in Height of Lamps.

found with very little trouble. The curve for a circular area is easily drawn; it is only necessary to take the radius of any given illumination on the illumination-curve which has been plotted from the street-lighting measurements, and to plot that radius against the area of a circle of that radius. Square and triangular areas would be more troublesome, but the lower part of the characteristics for widely-spaced lamps in ordinary street-lighting is very flat, and the last part must be horizontal.

SECTION II.

PHOTOMETRY.

Photometry, as has already been observed, has hitherto been confined chiefly to scientific laboratory research, and to the commercial testing of gas. The former branch of the subject does not seem to have been very attractive, probably because it is one of the least accurate kinds of measurement. Numerous attempts have been made to banish photometry altogether from the physical laboratory. The radiometer, it was hoped, would supplant it; but the effect of the luminous rays, when separated from the thermal, is very feeble. The thermopile has been used to indicate the whole radiant energy by means of electrical apparatus, and the dark heat rays have been successfully filtered out by selective absorption. Considerable accuracy is possible with the best thermopiles, but the apparatus is unsuited for ordinary engineering work, and great precautions must be taken to avoid any changes of temperature or unsuspected radiation of heat, which would appear in the results as though it were part of the light to be measured. Photometers depending on chemical combinations of gases, &c., may also be dismissed, as either insufficiently developed or unsuitable for the present purpose. Photographic methods have been suggested; daylight and sunlight have been thus investigated by Sir H. Roscoe and by Mr. W. Brennand,[1] and the Author has made several attempts, with very encouraging results, to measure illumination in this manner. The "bougie-metre-second" has been adopted by the International Photographic Congress, held at Brussels in the autumn of 1891, and promises to be a very useful quantity. The Author finds that an illumination of 5 candle-foot-seconds produces a very sensitive shade of grey on the bromide paper known as "Ilford slow." To measure an illumination of about 1 candle-foot, part of a strip of such paper was exposed for five seconds, and the other part was afterwards exposed at home, also for five seconds, to different illuminations, e.g., 0·8, 0·9, 1·0, 1·1, 1·2 candle-foot. The two parts of the strip were developed together in the same dish. This treatment produced a number of bands of different tone, forming a scale; and the tone of the test-strip could be compared with the scale, and its value estimated. The production of a scale by varying the length of exposure is much easier; but the relation between the time of exposure and the tone is very complex, and presents many difficulties. The photographic method could be employed for integrating the whole illumination of a street, by carrying about a sensitive strip in a systematic manner all over the district to be measured, occupying, say, half-an-hour for ¼ mile of street. The chemical development of a number of test strips can be carried out as rapidly as the calculation of a number of indicator-diagrams, and, like them, is to be valued for the permanent record of the measurements afforded.

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[1] Proceedings Royal Society, vol. xlix. Read December 11, 1890.

By a photometer, a gas-engineer means an assemblage of apparatus of different kinds, including meters, pressure-gauges, thermometers, balance, and other accessories, a remarkable feature of the collection being a great elaboration of cabinet-work and velvet curtains. Photometry in like manner suggests to a gas-engineer the art of manipulating and observing all these instruments, and co-ordinating the results for the purposes for which the tests are made. Lord Kelvin, on the other hand, has asserted that no one can want a better photometer than one composed of a pencil and a card. Dismissing the expensive paraphernalia which are needed, not for real photometry, but for gas-testing, the photometers proper can be divided into three classes:—the Bunsen, the Rumford, and the Foucault. The most common form of the first is a screen of paper with a grease-spot; the second, the one alluded to by Lord Kelvin, a rod, casting two shadows on a screen; and the third, a translucent screen, separated into halves by a partition at right-angles to it. The Bunsen photometer is almost invariably employed for gas-testing; the Rumford, or shadow method, is frequently used in physical laboratories; while the Foucault is a favourite in France, but has been recommended by Mr. Vernon Harcourt for gas-testing. The ordinary gas-testing photometer is used in the large majority of cases, for testing a flame of about 16 candle-power against a standard of 2 candle-power. Small differences are looked for, and a wide range is rarely needed. The dimensions of the apparatus being limited by the cabinet-work and upholstery, and a pair of candles being frequently employed as a standard, a shadow photometer cannot well be used, since the edge of the shadows under these circumstances would not be sufficiently sharp to enable an easy comparison to be made. The popularity of the Bunsen instrument is partly accounted for thus. While the object of this Paper is rather to discuss photometers for measuring illumination, two modifications of the shadow-photometer, devised by the Author in the course of his investigations, may be here described.

A disadvantage of the ordinary rod-and-screen instrument is that, as commonly arranged, a considerable part of the screen, which is useless, is illuminated by the two lights simultaneously, while the shadows which have to be observed receive only half this illumination. The eye is thus dazzled, and there are generally practical difficulties in increasing the width of the shadows. The Author has arranged a strip of looking-glass to cast a shadow from one light on a screen; and has arranged it at an angle of 45°, so that the light from the other source is superposed upon the shadow. Adjustment is made so that one edge of the shadow coincides with one edge of the reflected beam; when a balance is obtained, the whole screen is of the same tone, with the exception of a narrow strip of shadow or added illumination, if the reflected beam is wider or narrower than the shadow.

While testing such a mirror-shadow photometer, with the object of finding the correction to be made for the absorption of the mirror, the Author desired to keep a check on two practically equal lights, and for this purpose arranged an ordinary shadow photometer. It was convenient to place the rod and screen horizontally, and, to bring the two shadows into juxtaposition, the rod was placed nearly in a line with the two lights. With this arrangement, it is clear that the shadow thrown by either light is most intense in the neighbourhood of that light, and falls off at a distance. The intensity of two shadows diminishes in opposite directions, and they match each other in tone at a certain point. If the lights are equal in candle-power, and are symmetrically arranged, the match will be found at the middle point between them. If they are of unequal power, the position of the point at which the two shadows match will be displaced towards the weaker light. A scale can be arranged, by which the relative strength of the lights may be read off by simple inspection. The Author is not aware that any direct-reading photometer has been previously used.

Let the scale A B, *Fig. 24*, be 5 feet long, and let the ends be immediately below the two lights which are fixed at this distance apart. Let the illumination due to each light at the middle point on the scale be one-tenth of the maximum illumination at the end of the scale, that is at the point nearest the light. $\cos^3 \theta$ then is $0 \cdot 1$, θ is 62° 20′, $\tan \theta$ is $1 \cdot 907$. The half-length of the scale is, therefore, 1·907 times the distance of the lamp from the scale. The half-length of the scale being 30 inches, the lamps must be fixed at 15·7 inches from the scale. If θ and ϕ be the angles of incidence at the matching point on the scale, the candle-power of the two lights being a and b,

$$a \cos^3 \theta, = b \cos^3 \phi,$$

and $\tan \phi + \tan \theta$ is a constant, being the length of the scale. The value of a being unity, that is, the standard of light, b can be found in terms of $\tan \phi$; that is to say, the scale in *Fig. 25* may be graduated in candle-power in terms of a. As horizontal measurements are generally taken, and as the light emitted by many lamps and flames differs at different angles, this form of photometer would be more useful if the scale were arranged vertically, and in the horizontal plane of the lights to be compared. It is not easy to read off the position at which the two shadows match, but the Author believes that, with a little practice and a choice of the best ratio of the length of scale to the distance of the lamps from it, very quick readings could be taken, and that this photometer may be useful to makers of glow-lamps. It is essential that the scale be perfectly flat.

Fig. 24.

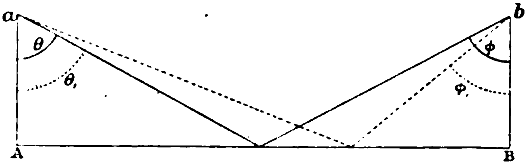
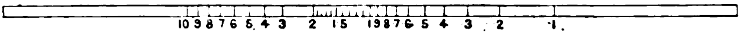


Fig. 25.



SCALE OF DIRECT-READING PHOTOMETER.

ILLUMINATION-PHOTOMETERS.

The first photometer that appears to have been designed and employed for measuring illumination was that of Professor Weber. A standard lamp is arranged in a box at one end of a horizontal tube. In this tube, and capable of sliding in it, is a translucent screen of opal, or ground glass. A reflecting prism throws the light down a vertical cross-tube, and by another reflecting prism into an eye-piece. At the top of the vertical tube is a similar piece of translucent glass, and these two screens are observed together. The screen in the horizontal tube is moved until a balance is obtained, when the two screens appear to be equally bright. By a suitable scale the illumination is read off. This instrument does not appear to give a wide range, and the horizontal tube would have to be very long for measuring feeble illuminations. In a later pattern this defect is reduced by the introduction of a polariscopic arrangement, in which the light is extinguished by the rotation of Nicol prisms. It does not allow measurements to be made near the ground, and, as it would be difficult to arrange a standard height for such measurements, it seems desirable that, for purposes of comparison of street-lighting, the illumination on the ground or a few inches above it should be considered.

Another somewhat similar instrument has been devised by Professor Mascart, and has been used by him in numerous photometric tests of illumination in Paris. He, like Professor Weber, employed a modification of the Foucault photometer, but experienced great difficulty in finding a screen which would transmit light in proportion to the cosine of the angle of incidence. With homogeneous paper, the transmitted light diminished more rapidly than the cosine, and less rapidly than the squared cosine. He ultimately used the kind of screen employed by Foucault, which consists of two sheets of glass, separated by a layer of starch.[1]

Portable photometers, and a street-photometer on wheels, had been used for measuring candle-power; but little attention was paid to the measurement of illumination until Mr. Preece described his illumination-photometer before the Royal Society, on the 21st of June, 1883. This is also an arrangement of a Bunsen screen. A small glow-lamp, *Fig. 26*, is fixed in a box, carefully blackened in the interior. Over the end is stretched a Bunsen screen of paper, on the middle of which is a grease-spot. At about 12 inches from the latter is another screen on which drawing-paper is fixed. The grease-spot is so screened that no light falls upon it beyond what is reflected from the screen. At the end of the box opposite the Bunsen screen is an eye-piece, consisting of a plain tube. To make an observation, it is only necessary to place the instrument so that the reflecting screen receives the illumination which it is desired to measure, and to alter the electric current of the glow-lamp by means of an adjustable resistance, or a rheostat, until the grease-spot becomes invisible. Mr. Preece found by experiments that the candle-power of the glow-lamp increased as the sixth power of the current. The current in amperes thus gave, for a particular lamp, a constant whose sixth power expressed the illumination measured. Professor Kittler, of Darmstadt, and Captain Abney independently corroborated this function, and recent observations[1] show that, in modern glow-lamps of 8 candle-power, the candle-power varies as the current raised to powers of from 5·3 to 6·9. By the use of a reflecting screen, Mr. Preece avoids the difficulty met by Professor Mascart; but, for feeble illuminations, a serious loss of the dim light to be measured is entailed. Having had the opportunity of making a considerable number of measurements with Mr. Preece's 1883 photometer, the Author ventures to comment upon some of its details, and to point out modifications which he has made in adapting it for street-photometry. The instability of a glow-lamp, as a standard, was alluded to by Mr. Preece in his original Paper, but no sudden change is likely to take place in the course of an evening's work. All such secondary standards should be calibrated immediately

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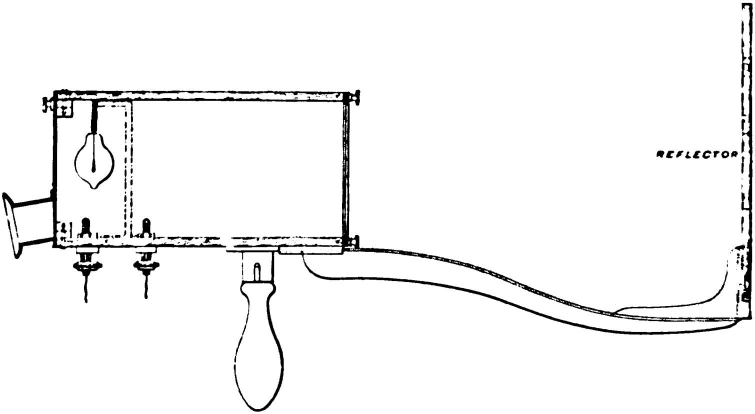
[1] Société des Électriciens, vol. v. p. 103.

Fig. 26.



Sectional Elevation.

PREECE PHOTOMETER.

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[1] Technology Quarterly, American Academy of Sciences. Reprinted in *The Electrician*, vol. xxviii. p. 112. Also a Report on Tests of Lamps, published in *The Electrician*, July 15th, 1892.

before and after a series of observations. Sensitive ammeters had not been constructed in 1883, and a differential-galvanometer method was employed for measuring the current. The manufacture of both primary and secondary batteries has made such important strides since that date, that it is no longer necessary to encumber the observer with ammeter or galvanometer. A portable secondary battery, worked at about one-third of its nominal output, may be relied upon for an evening's work, especially if the current be used only during an actual measurement. With such a photometer, the rheostat may be calibrated directly in luces, or candle-feet. A most important field for illumination-photometry exists in arc-lighting, the greatly-debated question of the usefulness and quality of arc-lighting must be reduced to measurement before any practical discussion can take place upon it. Although it is possible to use a glow-lamp for about an hour, with so large a current that the light emitted by it is nearly identical with that of an arc, it is obvious that, when a rheostat is used for diminishing the light, the colour becomes more yellow, and finally, in the measurement of feeble illuminations, becomes orange and dull red. It is by no means impossible to compare the illumination produced by lights of very different colour with a high degree of accuracy, but considerable practice is necessary. Captain Abney and General Festing can estimate the comparative luminosity of a patch of scarlet and a patch of green, brown, or any other colour. The feat seems impossible, and the accuracy, within 2 per cent., incredible to any one who has been inconvenienced by the difficulty of balancing the colour of a candle-flame against the light of an arc-lamp. The secret of Captain Abney's success is his method of rapidly varying one or both lights, making many and quick changes on each side of the real balance, by the oscillation of a light and easily-moved lever. After very little practice, it is not difficult to make the two lights vary alternately by equal amounts and to decrease this variation until it is hardly sensible. The muscular sense of moving the lever enables its mean position to be found, or the alternate motion may be continued for a couple of seconds, while the observer looks at the scale and estimates the middle position. It does not follow that when the balance is obtained by this method, the two illuminations appear identical to the eye, and it is only by making rapid oscillations on each side of the mean position that the true reading can be discovered. This kind of observation is uncommon in physical measurements, and the accuracy which may be obtained by it will hardly be believed without practical experience.

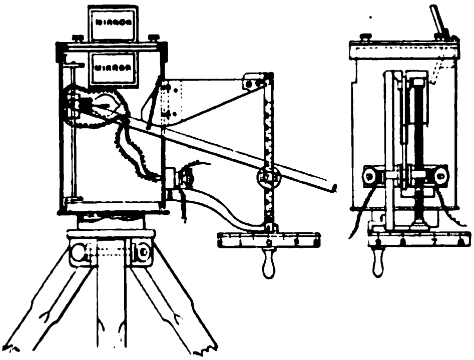
The rheostat used in connection with the Preece photometer was an ordinary plug resistance box, one of the most difficult pieces of apparatus to use quickly, and quite unsuitable for the method of rapid and gradually diminishing variations. A sliding resistance consisting of a single straight wire might be used, and the Author has tried a resistance composed of 150 turns of No. 30 tinned-iron wire, on a rod 1 foot 6 inches long. Quick and accurate readings could be obtained thus, but the colour difficulty is a serious objection, and one which can be avoided by other means.

Unlike other Bunsen photometers, the Preece photometer employed one side of the screen only, and the observer looked directly at the grease-spot. The theory of the Bunsen photometer shows that a balance can only be a measure of the equality of the illuminations, when the screen is perfectly opaque, and the spot perfectly transparent. Again, the screen of drawing-paper subtends a certain solid angle to the Bunsen spot and this angle is arbitrarily fixed. The readings on this photometer, though fairly accurate, as proved by experiment, depend on the combined result of several different and arbitrary factors.

A modification was designed by the Author in conjunction with Mr. Preece in April 1884, with the view of obviating the colour difficulty and the liability of error produced by different kinds of Bunsen screens. The usual arrangement of screen with two mirrors was employed, allowing both sides of the spot to be seen simultaneously. Upon a tripod, a cylindrical case, *Fig. 27*, is covered at the top by a horizontal Bunsen screen, and two observing-mirrors are inclined at a suitable angle. A glow-lamp slides on a vertical rod, and connection with external terminals is maintained by coiled wires. The lamp is moved by a lever which pushes it in opposition to a spring. The lever is pressed against the cam, and bears against the roller. This roller is mounted on a nut which traverses a vertical screw. Its position may be read on a scale. At the lower end of the screw is a handle and a graduated wheel. The cam is shaped to such a curve that when the nut moves through any given distance, the displacement of the lamp is as the square of that distance; the light of the lamp being adjusted to any required power, balances a given illumination when the scale reads the unit. A balance being effected for any other illumination, its value in terms of the said unit may be read off on the scale. It is not necessary to measure the distance of the filament of the lamp from the screen. This instrument is easy to use, but the range is only from one to ten, and cannot easily be increased. A sliding rheostat and an ammeter were used for maintaining at a fixed value the current required to balance the unit illumination.

In recommencing the study of illumination photometry, after an interval of nearly eight years, the Author took up the photometer in a somewhat modified form. He wished to make the measurements as near the ground as possible, and therefore, avoiding the tripod, he arranged a Bunsen screen 6 inches from the ground. To see both sides simultaneously would need three mirrors, and would necessitate a very limited view. As it is very much easier to make observations without an eye-piece, using both eyes, he decided to return to the observation of one side of the Bunsen screen only, and to make an empirical correction if necessary. A 6-inch cube, covered by a Bunsen screen at the top, and open at the side, was used. Some of the unsuccessful attempts will be briefly described, for the purpose of saving the time of other experimenters. A piece of plate looking-glass was fixed at an angle of 45°, and a 1-candle electric-lamp, operated by a secondary battery, was arranged to illuminate it. It was at once found that no balance could be obtained when the screen was viewed from a point directly above it, without a very great disproportion between the illumination of the two sides of the Bunsen screen. It is usual to observe a Bunsen spot from a direction inclined at a small angle to the surface of the screen, and to compare the appearance of the two sides. Owing to the imperfect translucency of the spot, and the often imperfect opacity of the rest of the screen, a complete disappearance is not obtained, even

Figs. 27.



Sectional Elevation. Side Elevation.

PREECE AND TROTTER PHOTOMETER.

when a balance is effected. Again, if the illumination on one side is adjusted so that a complete disappearance of the spot is obtained, when viewed from a certain direction, the spot will reappear if this direction is changed. It is necessary, therefore, in using a photometer which makes use of one side of the screen only, to fix upon a definite direction from which it is to be viewed. As eyepieces are highly objectionable where accurate discrimination of delicate differences of tone are desired, the perpendicular direction of view is almost essential in this form of photometer. A ground-glass screen in front of, and immediately in contact with, the mirror, was tried. This was found unsatisfactory, but the instrument at once assumed a practical form when the mirror was replaced by a piece of white paper. In all subsequent work white Bristol board has been used, and this part of the photometer will be called the reflecting screen.

Numerous experiments were made with different kinds of Bunsen spots. The perpendicular direction of view modifies the behaviour of such spots very materially. Tracing-paper stretched over Bristol board, in which a star-shaped hole has been cut, was found to be far superior to any grease-spot, and the two sheets of thin paper used in the " Leeson " disk were unnecessary, since only one side of the screen was used. The best kind of tracing-paper is that which, while having as little colour of its own as possible, is darkest when laid on a black surface. This was used in the earlier work. Tracing-paper with a milky or opaline body does not give so sensitive a spot. For practical use, especially in street-work, the Bristol board should be mounted on glass, and the tracing-paper, tightly strained, should be pasted over it, taking care not to press it into contact with the glass. The under surface of the glass was blackened, leaving $\frac{1}{16}$ inch round the star.

Further experiments, with the view of finding the most sensitive kind of Bunsen spot, suggested the use of ground glass instead of tracing-paper, and consideration of the fineness of the ground surface suggested the trial of clear glass, or of a simple cardboard screen, with a star-shaped hole cut in it. This was found to be far more sensitive than any other arrangement, and was used in all the later work. The difference in the colours of the standard lamp and of the light to be measured, is more marked than with Bunsen screen with tracing-paper, but the great sensitiveness more than compensates for the disadvantage. It is evident that in an ordinary greased-paper disk, or with a Leeson disk, the two sides of the opaque part are illuminated by the two coloured lights, while the grease-spot acquires an intermediate colour, owing to the mingling of the two lights. With a perforated-screen photometer, the reflecting screen is illuminated by the standard lamp, and is seen through the perforation in the horizontal disk. The Author has found little difficulty in matching the illumination from an arc-lamp, even when the standard lamp gave a light of about the same colour as that of a candle. He finds that greater accuracy is possible between 0·6 candle-foot and 0·2 candle-foot than with higher or lower illuminations. The Joly paraffin-block photometer has been tried, but the Author does not find it to be sufficiently sensitive for illuminations of less than 0·5 candle-foot.

The electric lamp was mounted in a box, so that it stood 5 inches above the ground. The object of raising it above the level of the middle of the reflecting screen was to prevent any light from falling directly on the underside of the Bunsen screen, and many erroneous measurements were made before this precaution was taken. Telescopic tubes were used to shut out stray light from the reflecting screen; these tubes, when fully extended, measured 1 foot 4 inches in length. The storage-battery consisted of four Lithanode cells, manufactured by the Mining and General Electric-Lamp Company. Two of these are quite capable of running a $\frac{3}{4}$-candle lamp, at a fair brightness, for ten hours; but in order to allow a good margin, two more cells were connected in parallel. These have proved to be sufficient for the purpose, and no appreciable change in candle-power has been observed between the preliminary calibration and the one which followed each evening's work. A slightly higher power is given immediately after charging, but a quarter-of-an-hour's continuous discharge seems to bring the batteries into a very steady condition. The lamp was lighted for as short periods as possible, about ten seconds being sufficient for each reading.

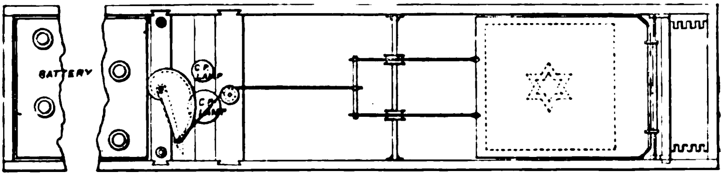
To calibrate this photometer, it was laid on its side, the Bunsen screen being vertical and facing a lamp. Small paraffin-lamps, turned down to give about 1 candle-power, were generally used for this purpose, no measurements being made until they had burned for half-an-hour. The distance from the Bunsen screen to one lamp, when a balance had been obtained, was easily measured, but it was not evident from what point on the reflecting screen the distance of the other lamp should be taken. A point was taken at random, viz., the extreme back of the cube. The lamps were placed at different distances along lines laid down at right-angles, the extreme positions giving an illumination at the photometer of about 0·003 candle-foot, that is, a candle at 18 feet.

The distances were plotted as rectangular co-ordinates. The points fell for the most part closely on a straight line, showing that the photometer followed the usual law of the squares of the distances. They curved off a little near the origin, as if the lamp which illuminated the reflecting screen increased in candle-power for very short distances; this was probably due to the larger solid angle of light falling on the reflecting screen, and to internal reflection from the back of the Bunsen screen. But the straight line cut the axis at a point 5 inches from the origin. A point 5 inches from the back of the cube was therefore the proper point from which measurements should be taken, in order that the law of the squares of the distance might be followed with fair approximation. Measurements were made with this photometer in several parts of London.

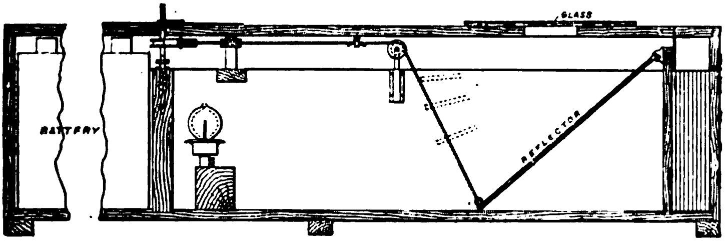
As a typical example of an old-fashioned gas-lit street, one which is undoubtedly known to all members of the Institution of Civil Engineers, Great George Street, Westminster, was the scene of the first street-lighting measurements, and the first observation was made 2 feet from the curb, immediately opposite the entrance to the Institution. The illumination was found to be 0·03 candle-foot. This was read off on a measuring tape graduated directly in candle-feet, the divisions being the reciprocals of the square of the length in feet. For feeble illuminations, it was found that stray light, especially from distant lamps, fell on the reflecting screen, and caused the readings to be too low in spite of the telescopic tubes which were used. Illuminations of 0·005 candle-foot are not uncommon in gas-lit streets. This corresponds to a candle at about 14 feet 2 inches. In streets lighted by arcs, a minimum of 0·025 is frequently found; this corresponds to a candle at 6 feet 4 inches. A complete tube connecting the lamp with the photometer, is therefore practically out of the question, and the Author proceeded to experiment on different methods of diminishing the light.

It is convenient, especially for feeble illumination, to have the Bunsen screen at least 3½ inches square, and the star-shaped hole or grease-spot should not be less than 1¼ inch across. Many experiments were made with lenses, both concave and convex, but it was found that a range of movement of at least 2 feet 6 inches was necessary, and it was difficult even then to get a uniform illumination on the reflecting screen. The eclipsing device used in dissolving views, required fully 2 feet. Photographically-shaded glass screens were tried, also a pair of lenses sliding over each other, as in a heliometer. The latter device would have succeeded, but in low illuminations an image of the lenses appeared. The Author finally adopted the method of inclining the reflecting screen at different angles. As at first arranged, the screen was mounted symmetrically on a horizontal axis, and a pointer was geared to the axis in the ratio of 1 to 12. The readings for low illuminations were too close together, and, owing to the reflection from the interior of the box, total darkness could not be obtained, even when the lower surface of the Bunsen screen and all the internal parts were carefully blackened. The reflecting screen was then mounted on an axis passing through its upper edge, and was arranged so that it could fold up quite out of the beam. In order that a convenient scale might be provided, motion was given to the reflecting screen by a fine chain wound upon a snail-cam. The cam was designed upon the assumption that the illumination on the screen would be proportional to the cosine of the angle of incidence of the light upon it. This is not strictly the case, especially as a convex lens was used in many of the tests to increase the available light from the electric-lamp. The object of the snail-cam was merely to spread the divisions of the scale more evenly, and did not aim at uniform division. The scale was empirically calibrated with a standard candle. This photometer (*Fig. 28*) was constructed by the Author. Various alterations were afterwards made by the Mining and General Electric-Lamp Co., and by Messrs. Swinburne & Co.

Figs. 28.



Plan with cover removed.



Sectional Elevation.

TROTTER PHOTOMETER.

SECTION III.

RESULTS OF MEASUREMENTS.

The principal object of the measurements of illumination which have been made by the Author and his assistants during the past winter, has been to ascertain the nature of the distribution of light in various streets and public places; a second object was to find the amount of illumination in candle-feet for such places; and the last and least important, from the present point of view, was to deduce the candle-power of the lights which produced that illumination, since that is a matter of ordinary photometry.

While the observed distribution of illumination was found to agree very closely with the general results which might have been arrived at by calculation, the real point of importance for the engineer who has to carry out the lighting of a given street or building to know is, what degree of uniformity is desirable for a particular case; how that degree may be attained by the proper planting of lamp-posts; and the selection of the proper height of such posts. This question of distribution being settled, the amount of illumination becomes a simple question of candle-power. No definite rules can be given as to these matters, and whether this or that street is well or sufficiently lighted, must remain largely a matter of opinion. It seems that 0·03 candle-foot is the lowest point that should be reached in a well-lighted street.

The degree of uniformity, and the amount of illumination in candle-feet may be found by actual measurement, and may be expressed in figures; but the mode of lighting, the arrangement of the lamps, and their height above the ground, while influencing these results, have a very important bearing upon the comfort and usefulness of the general effect.

The lighting of interiors is yet more difficult to describe in general terms, and the Author has made no attempt to reduce it to candles per cubic foot of space, as has been done by Professor Mascart[1] and Mr. Fontaine, but he will confine himself to the records of observed illumination in a few typical cases.

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[1] Bulletin de la Société Internationale des Électriciens, vol. v. p. 102.

South Kensington Museum.

One of the first examples of lighting which was examined by the Author was that of South Kensington Museum, by permission of General Festing. The Sculpture Court, containing the Trajan Column, is well and sufficiently lighted by Brush arc-lamps placed at the very considerable height of about 50 feet. This court is 135 feet by 60 feet, the height to the ceiling is 83 feet. The illumination is quite sufficient for the artists who are to be found there in the evening, sketching architectural and other details. The great size of many of the objects exhibited in this court, prevents more than seven or eight lamps being seen from any one position. It was found that the illumination on the ground at any point depended simply on the number of arc-lamps in sight at that point. The following readings were taken with the 6-inch cube photometer:—

Candle-feet	0·55	0·5	0·6	0·5	0·8	0·7
Number of arcs in sight. . .	6	6	7	6	8	7

In the Silversmiths' Court the illumination was found to be 2·6 candle-feet, with ten arc-lamps in sight; in the Japanese Court 1·6 candle-foot, with eight lamps in sight; in the Great Hall, near the centre, 2·4 candle-feet, with nine lamps in sight, the lamps being about 25 feet from the floor. In the gallery over the Silversmiths' Court, near the bookbinding cases, about 3·5 candle-feet were recorded. Opposite the refreshment-room, in the corridor lighted by glow lamps, the illumination was found to be 0·65 candle-foot. A very easy way of counting the number of lamps which can be seen by an eye placed at the photometer-spot, is to hold a pencil upright on the screen; this casts a number of shadows radially, and these may be counted.[1]

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[1] In the Report on the Action of Light on Water-colours (published as a Blue Book (C. 5453), 1888, by Dr. Russell and Captain Abney), measurements made by General Festing with the Preece photometer are given. North-east water-colour gallery (gas), 1·81 candle-foot; south-east water-colour gallery (gas), 2·32 candle-feet; Jones Bequest gallery (electric glow-lamp), 1·72 candle-foot; Raphael gallery (arc), 2·26 candle-feet; Sheepshanks gallery (arc), 3·12 candle-feet.

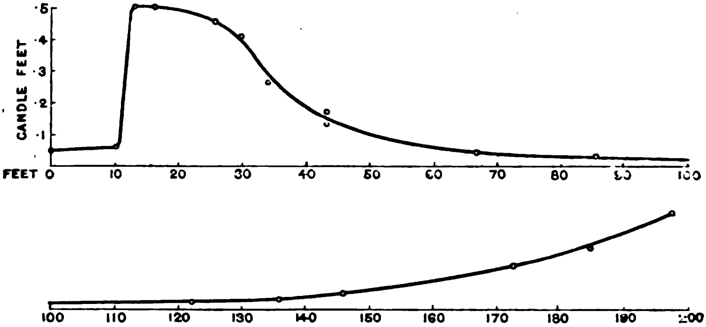
The mean natural illumination of daylight measured for the blue rays in one of the galleries during April and May was about 13 candle-feet. On thirteen days it exceeded 20 candle-feet; the maximum was about 36.

CHARING CROSS AND CANNON STREET STATIONS.

By permission of Sir Myles Fenton, measurements were made at Charing Cross and Cannon Street Stations. The arc-lamps at Charing Cross are about 18 feet from the platform. The maximum illumination on the evening of January 29, 1892, was to be found between 15 and 22 feet from the point below the lamp, and varied from 0·4 to 0·5 candle-foot. The minimum was about 0·05 candle-foot. There are fourteen arc-lamps in the station, arranged somewhat irregularly in four rows. The station covers about 9,050 square yards. There are, therefore, roughly, 646 square yards to each lamp.

Two sets of measurements were made at Cannon Street Station, one with the 6-inch cube photometer, and another, on the date already mentioned, with the improved form. These measurements agreed fairly well with each other; the first pattern gave low readings for low illuminations, owing to diffused light on the reflecting screen. *Fig. 29* shows the distribution of illumination along the main-line arrival-platform, starting from the point beneath a lamp enclosed in a lantern of clear glass. There is a deep shadow of 0·05 to 0·06 candle-foot beneath the lamp; the edge of this shadow is probably sharper than is represented by the curve. All the readings are given as small circles on the curve. The lamps are an old form of the Brockie pattern, and take 15 amperes; they are hung at about 35 feet from the platform. There are eight lamps, arranged symmetrically. The station

Fig. 29.



ILLUMINATION-CURVE ALONG MAIN-LINE ARRIVAL-PLATFORM, CANNON STREET STATION.

covers about 13,900 square yards, giving about 1,740 square yards to each lamp. The minimum is about 0·025, and maximum 0·35, to 0·4 candle-foot, distinctly less than at Charing Cross; but the greater height of the lamps prevents the glare which is to be found at the latter station. Assuming the volts of the lamps to be about the same, the watts expended at Charing Cross are about 15 per cent. greater than at Cannon Street. The difference in illumination is greater than this; but, owing to the irregular arrangement of the lamps at Charing Cross, an exact comparison could not be effected unless a complete survey of the station were made.

CITY OF LONDON.

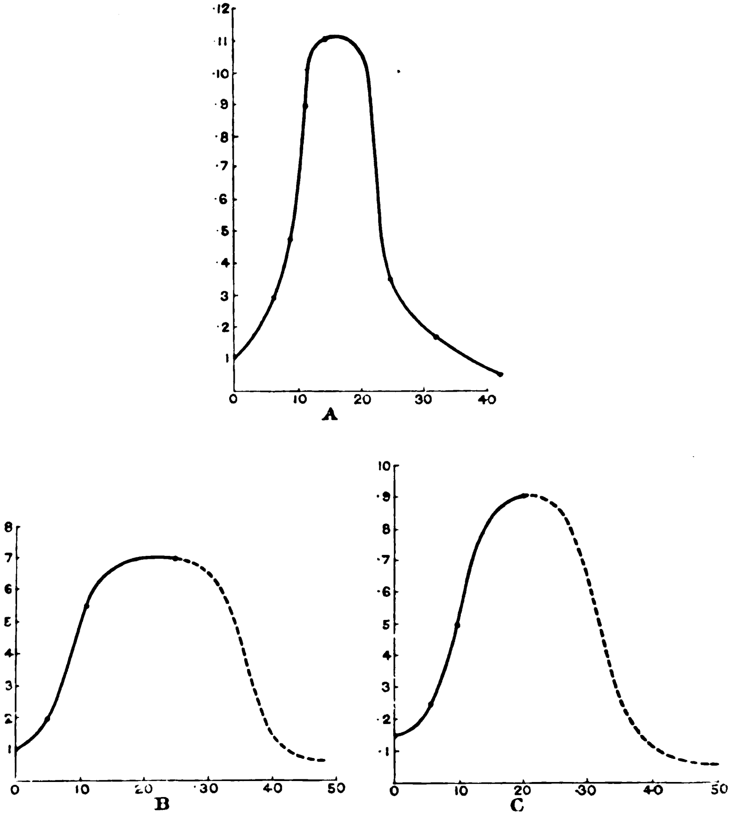
The street-lighting in the City has been measured by the Author on several occasions. A very large number of repeated observations would be necessary to give an exact result, since there is a considerable variation of light when the arc-lamps "feed." *Figs. 30* and *32* give illumination-curves of different lamps at different times. The three curves A, B, and C (*Fig. 30*), are picked from a number, as the best performances of the lamps. In these curves all the readings in any one set of observations are recorded. None have been suppressed as doubtful. The curves are drawn to represent the probable distribution of illumination as nearly as possible. The horizontal distances are given in feet, and an arbitrary scale of candle-feet has been used; that is to say, it has no relation to the height of the lamp, as in the first section of the present Paper. In several of the highest cases it was noticed that the light was not thrown uniformly, owing to the formation of the crater on one side, perhaps on account of bad setting of the carbons.

Fig. 33 gives the illumination-curve of a lamp in Cornhill, measured along the diagonal line in the direction of another lamp. A considerable crowd had collected when seven readings had been taken, and it is assumed that the remainder of the curve would be symmetrical, as shown. *Fig. 31* is the curve C (*Fig. 30*) on another scale. The maximum light being given at about 45°, and $\cos^4 45°$ being 0·25, the value of the illumination at the maximum is to be found on the scale of candle-feet, at a height equal to 0·25 of the height of the lamp, this height being measured in feet on the same scale as that of the horizontal distance. The curve is, however, so flat and uninteresting that the Author only gives it as an example.

In the course of a very careful measurement of the lighting in

Queen Victoria Street, on the 29th of January, 1892, it happened that the light of the three lamps was, during the greater part of

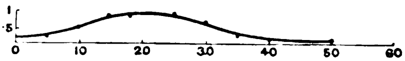
Figs. 30.



ILLUMINATION-CURVES OF ARC-LAMPS IN THE CITY.

A. Lamp opposite Brush Electrical Engineering Corporation's Show Rooms. Chequered glass.
B. Lamp near the General Electric Supply Company's offices. Figured glass.
C. Lamp with chequered or square moulded pattern on the glass.

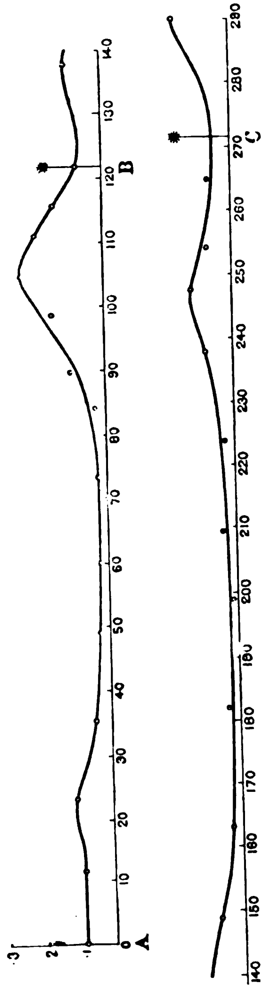
Fig. 31.



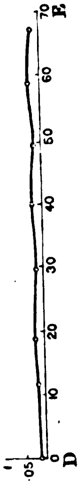
ILLUMINATION-CURVE C, FIG. 30, REDUCED TO FIT THE $\cos^4\theta$ CURVE.

the test, below the average. A plan of the portion of the street, corrected from the ordnance map, is given in *Fig. 34.* The three lamps are marked A, B, C, and a line across the street at the minimum is marked D E. The illumination-curves in *Figs. 32* show the actual readings. Starting from A, the illumination was 0·1 candle-foot at the foot of the lamp-post. A few seconds later, at a distance of 11 feet, before another reading could be taken, the lamp fed, and the reading at this point was the same. The measurements were continued without interruption, and the early ones probably represent the lowest illumination that is to be found

Figs. 32

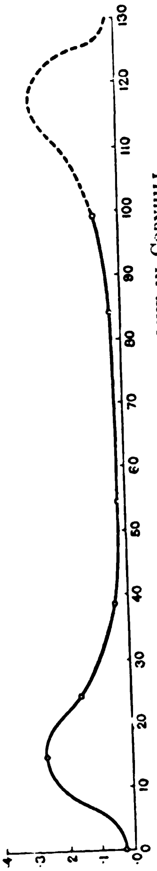


Illumination-Curve along the line A B C, *Fig. 34.*



Illumination-Curve along the line D E, *Fig. 34.*

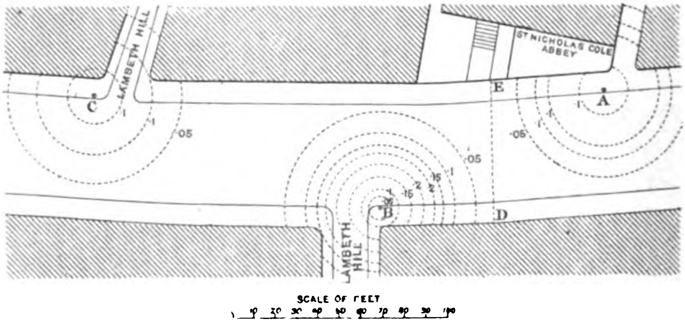
Fig. 33.



Illumination-Curve along a Diagonal Line in Cornhill.

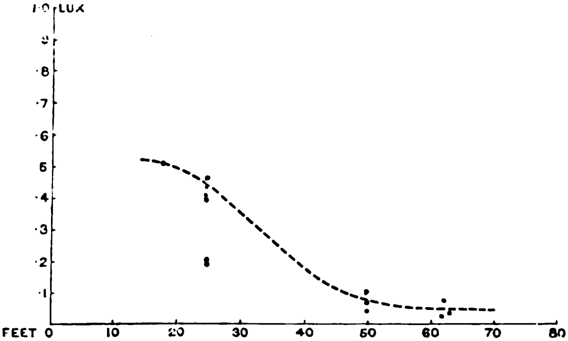
under these circumstances. On approaching B the light was good, and was a fair average of what the Author has found in some dozen or more tests. On starting towards C, lamp B fed, and C appears to have been below the average of this series of measurements. The measurements of distance were made with a tape; the assistance of the police-constables, kindly provided by Inspector Fraser, greatly facilitated the work, by diverting the traffic and by keeping off bystanders. The contour-lines are practically circles. It has been assumed, in the circles drawn in *Fig. 34*, that lamp C was burning well. If the contour of 0·04 candle-foot had been drawn, it would probably have been of the hour-glass kind, just looping on to the pavement near the minimum. The arc-lamps appeared to be about 17 feet 8 inches

Fig. 34.


LAMBETH HILL
ST NICHOLAS COLE ABBEY
C
E
A
·1
·1
·05
·05
·05
·1
·15
·2
·2
·15
B
D
LAMBETH HILL
SCALE OF FEET
10
20
30
40
50
60
70
80
90
100

CONTOUR-LINES OF EQUAL ILLUMINATION IN QUEEN VICTORIA STREET, LONDON.

Fig. 35.



VARIOUS MEASUREMENTS OF ILLUMINATION OF ARC-LAMPS IN THE CITY OF LONDON, MADE BY MR. PREECE.

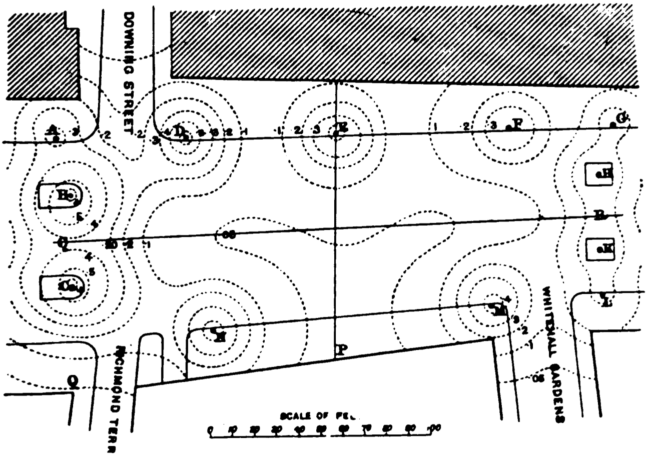
high, and the distance of the lamps apart was about 6·5 times their height.

A number of measurements, made under the direction of Mr. Preece, with his photometer, on different dates, and in different parts of Queen Victoria Street, are represented in *Fig. 35*, and an attempt has been made to draw a curve among them. The ordinates are given as decimals of a lux.

Whitehall.

On the 11th of February, 1892, a careful survey of Whitehall was made. *Fig. 36* is a plan of the part of the street between Downing Street and Whitehall Gardens. The gas-lamps are marked A to N, both on the plan and on *Figs. 37*, *38*, *39*, and *40*, which give the illumination-curves along the measured lines. Only a single reading near the minimum has been suppressed, being obviously wrong. The Author has been informed by Messrs. Sugg & Co. that the lamps are of the following description:—The small side lamps are "Whitehall" pattern, and are of 90 candle-power, consuming 20 cubic feet per hour. The large lamps are of the "Westminster" pattern, of 270 candle-power, consuming 50 cubic feet per hour.

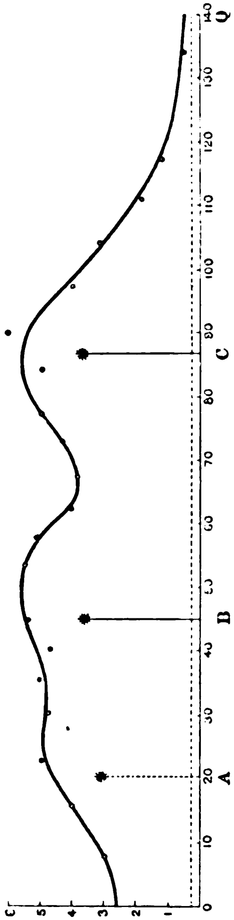
Fig. 36.



Contour-Lines of Equal Illumination in Whitehall, Westminster.

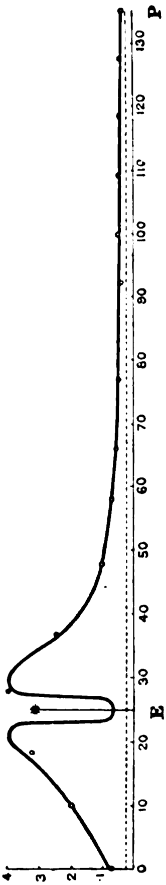
The illumination-curves show very clearly the effect of the shadow below the ordinary lamps. The large lamps at the "refuges" are provided with reflectors, which greatly lessen the shadow. Either because the transverse line A Q was not taken immediately below the lamps B and C, or by some error in the measurements, the shadow below these lamps does not appear plainly. From these illumination-curves may be seen the gradual rise of the minimum between A and D and between F and G, owing to the effect of the lamps at the refuges. The moon was

Fig. 37.



ILLUMINATION-CURVE ALONG THE LINE A Q, *Fig. 36.*

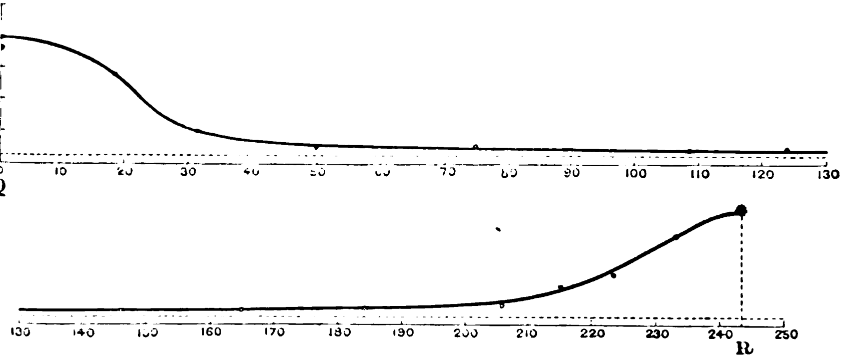
Fig. 38.



ILLUMINATION-CURVE ALONG THE LINE E P, *Fig. 35.*

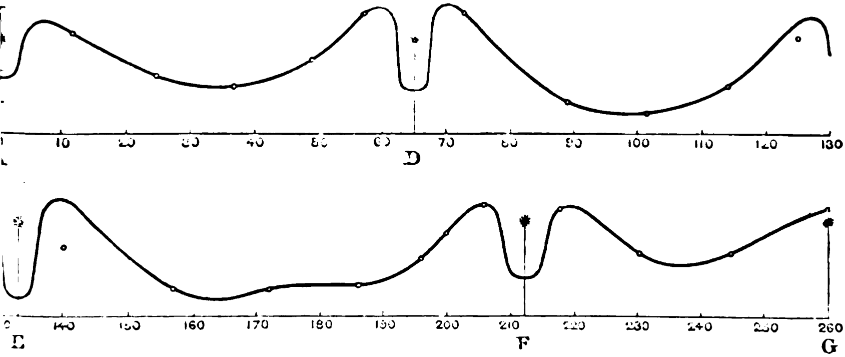
nearly full, and the sky was cloudless.[1] The dotted line represents the illumination 0·025 due to moonlight. The survey was completed at about 11 P.M. From these curves the contour-lines in *Fig. 36* were drawn, and from these contour-lines a model has been constructed by the Author, on the scale of 20 feet to an inch in plan, and 1 candle-foot to an inch in elevation.

Figs. 39.



ILLUMINATION-CURVE ALONG THE LINE Q R, *Fig. 35.*

Figs. 40.



ILLUMINATION-CURVE ALONG THE LINE A G, *Fig. 36.*

The difference between the illumination in Queen Victoria Street and in Whitehall was so very much less than the Author expected, that he repeated the measurements of the maxima and minima at Whitehall on the 25th of February, and proceeded at once to Queen Victoria Street, where he made twelve measurements of maxima and minima. He then returned to Whitehall and repeated the observations, thus ensuring that no error could be caused by variation in the power of the electric-lamp in the photometer. The measurements were in accordance with the results which have been given. An attempt to read a Bellows' French dictionary at different parts of the street seemed to show that the light in Queen Victoria Street was rather more useful, but the lighting in Whitehall is certainly less dazzling.

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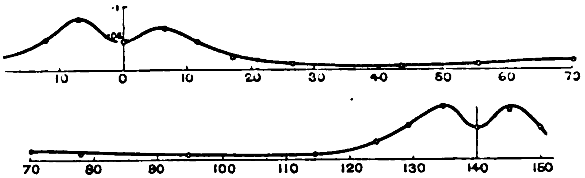
[1] Several attempts were made to measure street-illumination on moonlight nights when clouds were drifting over the sky. Although attempts were made to screen the photometer from the moon, the measurements were very irregular.

Ordinary Streets, Theatre-Lighting, &c.

Measurements of the illumination in streets lighted by the ordinary "5-feet" gas-lamp were made on several occasions. The illumination is so very feeble that exact measurement is very difficult. The maximum rarely exceeded 0·9 candle-foot. The illumination near the foot of an ordinary gas-lamp is very irregular, and is much cut up by shadows of the lantern frame. *Fig. 41* is the illumination-curve along the curb of the foot-pavement of Great George Street, Westminster. A slight increase midway between the lamps is due to a lamp on the opposite side of the street. The minima were about 0·005 candle-foot, an illumination a little greater than the value calculated by the cosine-cubed law. This is probably due to the reflection from surrounding buildings, or to general diffused light.

Fig. 41.



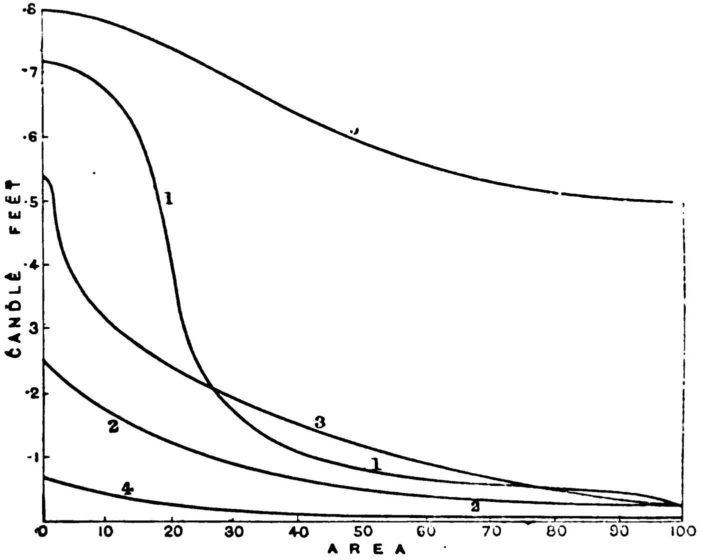
Illumination-Curve along the Curb of the Foot-Pavement of Great George Street, Westminster.

The illumination on the stage of the Lyric Theatre during the performance of "La Cigale" was 3·8 candle-feet without the arc- or lime-lights. On the stage of the Prince of Wales Theatre during the performance of "Maid Marian" the illumination was 2·9 candle-feet. The illumination in the trains of the Metropolitan and District Railways was measured on many occasions, and varied from 0·3 to 0·9 candle-foot, the photometer being held breast-high.

CHARACTERISTIC CURVES.

The results of the above-described measurements are summed up in *Fig. 42* as characteristic curves. The ordinates are candle-feet, and the horizontal scale is a percentage scale of areas. The maximum is 100. No. 1 is the characteristic of Queen Victoria Street, on the assumption that the lights are all burning at their best, as in curve C, *Fig. 30*. No. 2 is the characteristic of the same street, on the assumption that the lamps are at their worst, having just fed. No. 3 is the characteristic of Whitehall, the moonlight having been deducted. It appears that about one-half the area is better lighted than Queen Victoria Street. No. 4 is the characteristic of an ordinary gas-lit street. No. 5 is the characteristic, estimated approximately only, of the Architecture Court of the South Kensington Museum.

Fig. 42.



CHARACTERISTIC CURVES OF PRECEDING CASES.

CONCLUSION.

The Author, in conclusion, desires to record his indebtedness to Mr. Winny for assistance in experimental work and checking calculations; to Messrs. J. Leggat, J. E. Pierce, and W. G. Wallace, students at Finsbury Technical College, for their assistance in street-lighting measurements, which were sometimes continued until a late hour; to the Mining and General Electric-Lamp Company for alterations to photometers, for the loan of Lithanode batteries, and for the charging of the same on many occasions; to Mr. Preece for procuring him permission to make measurements in various public buildings; as well as to the police, without whose assistance the street-work would have been impossible.

APPENDIX.

Each of the following combinations is equal to one bougie-metre, or one-tenth of a lux.

TABLE I.—ROUND NUMBERS OF CANDLE-POWER.

Candle-power.	Feet.	Candle-power.	Feet.	Candle-power.	Feet.	Candle-power.	Feet.
0·01	0·3350	1·6	4·235	13	12·07	40	21·17
0·02	0·4735	1·8	4·490	14	12·52	42	21·70
0·03	0·5800	2·0	4·735	15	12·96	44	22·20
0·04	0·6700	2·5	5·290	16	13·40	46	22·70
0·05	0·7490	3·0	5·800	17	13·80	48	23·20
0·06	0·8200	3·5	6·260	18	14·21	50	23·68
0·07	0·8860	4·0	6·700	19	14·60	60	25·94
0·08	0·9470	4·5	7·100	20	14·97	70	28·00
0·09	1·0040	5·0	7·490	21	15·34	80	29·95
0·10	1·0580	5·5	7·860	22	15·70	90	31·75
0·20	1·4970	6·0	8·200	23	16·05	100	33·50
0·30	1·8350	6·5	8·540	24	16·40	200	47·35
0·40	2·1180	7·0	8·850	25	16·74	300	58·00
0·50	2·3680	7·5	9·170	26	17·07	400	67·00
0·60	2·5940	8·0	9·470	28	17·71	500	74·90
0·70	2·8000	8·5	9·760	29	18·02	600	82·00
0·80	2·9950	9·0	10·040	30	18·34	700	88·60
0·90	3·1750	9·5	10·032	32	18·94	800	94·70
1·00	3·3500	10·0	10·580	34	19·62	900	100·04
1·20	3·6700	11·0	11·110	36	20·08	1,000	105·80
1·40	3·9600	12·0	11·600	38	20·63	2,000	149·70

TABLE II.—ROUND NUMBERS OF FEET.

Candle-power.	Feet.	Candle-power.	Feet.	Candle-power.	Feet.	Candle-power.	Feet.
0·02235	0·5	3·770	6·5	20·08	15	65·0	27
0·08945	1·0	4·375	7·0	22·84	16	70·0	28
0·20080	1·5	5·020	7·5	25·8	17	75·0	29
0·35700	2·0	5·710	8·0	28·9	18	80·4	30
0·55900	2·5	6·450	8·5	32·2	19	109·3	35
0·80400	3·0	7·240	9·0	35·7	20	143·0	40
1·09300	3·5	8·050	9·5	39·4	21	181·0	45
1·43000	4·0	8·940	10·0	43·2	22	223·5	50
1·81000	4·5	90·800	11·0	47·2	23	321·5	60
2·23500	5·0	12·850	12·0	51·5	24	437·0	70
2·70000	5·5	15·100	13·0	55·8	25	571·0	80
3·21500	6·0	17·500	14·0	60·4	26	894·0	100

TABLE III.—ROUND NUMBERS OF COS^3 θ.

Cos^3 θ.	Cos θ	θ.	Tan θ.	Cos^3 θ.	Cos θ.	θ.	Tan θ.
		° ′				° ′	
0·995	0·9983	3 20	0·0582	0·360	0·7114	44 39	0·9878
0·990	0·9966	4 43	0·0825	0·340	0·6980	45 44	1·0260
0·980	0·9933	6 38	0·1163	0·320	0·6840	46 51	1·0670
0·960	0·9865	9 25	0·1658	0·300	0·6694	47 59	1·1100
0·940	0·9796	11 35	0·2058	0·280	0·6542	49 8	1·1560
0·920	0·9726	13 27	0·2392	0·260	0·6382	50 20	1·2060
0·900	0·9655	15 5	0·2695	0·240	0·6214	51 35	1·2610
0·880	0·9583	16 36	0·2981	0·220	0·6037	52 52	1·3210
0·860	0·9510	18 1	0·3249	0·200	0·5848	54 13	1·3870
0·840	0·9435	19 21	0·3512	0·190	0·5749	54 54	1·4230
0·820	0·9360	20 36	0·3759	0·180	0·5646	55 37	1·4610
0·800	0·9283	21 50	0·4006	0·170	0·5540	56 21	1·5020
0·780	0·9205	23 0	0·4245	0·160	0·5429	57 7	1·5470
0·760	0·9126	24 8	0·4480	0·150	0·5313	57 54	1·5940
0·740	0·9045	25 15	0·4716	0·140	0·5192	58 43	1·6460
0·720	0·8963	26 20	0·4949	0·130	0·5065	59 34	1·7020
0·700	0·8879	24 23	0·5180	0·120	0·4932	60 27	1·7640
0·680	0·8794	28 26	0·5415	0·110	0·4791	61 22	1·8320
0·660	0·8707	29 28	0·5650	0·100	0·4642	62 20	1·9070
0·640	0·8618	30 29	0·5886	0·090	0·4481	63 23	1·9950
0·620	0·8527	31 30	0·6128	0·080	0·4309	64 28	2·0930
0·600	0·8434	32 30	0·6371	0·070	0·4121	65 40	2·2110
0·580	0·8340	33 29	0·6615	0·060	0·3915	66 57	2·3500
0·560	0·8243	34 29	0·6868	0·050	0·3684	68 23	2·5240
0·540	0·8143	35 29	0·7128	0·040	0·3420	70 0	2·7470
0·520	0·8041	36 29	0·7395	0·030	0·3107	71 54	3·0590
0·500	0·7937	37 28	0·7664	0·020	0·2714	74 15	3·5460
0·480	0·7830	38 28	0·7945	0·010	0·2154	77 34	4·5360
0·460	0·7719	39 28	0·8234	0·008	0·2000	78 27	4·8930
0·440	0·7606	40 29	0·8536	0·005	0·1710	80 9	5·7590
0·420	0·7489	41 30	0·8847	0·002	0·1260	82 46	7·8800
0·400	0·7368	42 32	0·9174	0·001	0·1000	84 15	9·9310
0·380	0·7243	43 35	0·9517				

TABLE IV.—ROUND NUMBERS OF θ.

θ.	Cos^3 θ.	θ.	Cos^3 θ.	θ.	Cos^3 θ.	θ.	Cos^3 θ.
2	0·9982	22	0·7971	42	0·4103	62	0·103490
4	0·9928	24	0·7614	44	0·3722	64	0·084258
5	0·9886	25	0·7444	45	0·3535	65	0·075474
6	0·9836	26	0·7261	46	0·3353	66	0·067270
8	0·9712	28	0·6882	48	0·2995	68	0·052606
10	0·9551	30	0·6495	50	0·2656	70	0·040002
12	0·9357	32	0·6098	52	0·2334	72	0·029504
14	0·9135	34	0·5697	54	0·2031	75	0·017334
15	0·9011	35	0·5495	55	0·1888	80	0·005232
16	0·8883	36	0·5295	56	0·1754	85	0·000662
18	0·8603	38	0·4893	58	0·1488		
20	0·8271	40	0·4494	60	0·1250		

TABLE V.

Tan θ.	θ.	Cos θ.	Cos^2 θ.	Cos^3 θ.	Cos^4 θ.
	° '				
0·05	2 52	0·9987	0·9970	0·99600	0·991000
0·10	5 43	0·9950	0·9900	0·98500	0·982000
0·20	11 19	0·9806	0·9600	0·94300	0·922000
0·30	16 42	0·9578	0·9170	0·87900	0·841000
0·40	21 49	0·9284	0·8620	0·80000	0·743000
0·50	26 34	0·8944	0·8000	0·71500	0·640000
0·60	30 58	0·8575	0·7350	0·63000	0·540000
0·70	35 0	0·8191	0·6710	0·54900	0·450000
0·80	38 40	0·7808	0·6100	0·47600	0·372000
0·90	42 0	0·7431	0·5520	0·41000	0·305000
1·00	45 0	0·7071	0·5000	0·35300	0·250000
1·10	47 44	0·6726	0·4520	0·30500	0·204000
1·20	50 12	0·6401	0·4100	0·26200	0·168000
1·30	52 26	0·6097	0·3710	0·22600	0·138000
1·40	54 28	0·5812	0·3380	0·19600	0·114000
1·50	36 19	0·5546	0·3070	0·17100	0·094300
1·60	58 0	0·5299	0·2810	0·14900	0·079000
1·70	59 33	0·5068	0·2570	0·13000	0·066000
1·80	60 57	0·4856	0·2360	0·11400	0·055700
1·90	62 15	0·4656	0·2170	0·10100	0·047100
2·00	63 27	0·4470	0·2000	0·08930	0·040000
2·20	65 34	0·4136	0·1710	0·07090	0·029200
2·40	67 23	0·3846	0·1480	0·05680	0·021900
2·60	68 58	0·3589	0·1290	0·04630	0·016600
2·80	70 21	0·3363	0·1130	0·03800	0·012800
3·00	71 34	0·3162	0·1000	0·03160	0·010000
3·20	72 39	0·2982	0·0888	0·02650	0·007880
3·40	73 37	0·2821	0·0795	0·02240	0·006320
3·50	74 3	0·2748	0·0756	0·02080	0·005710
4·00	75 58	0·2425	0·0597	0·01420	0·003560
4·50	77 29	0·2167	0·0468	0·01020	0·002190
5·00	78 42	0·1959	0·0384	0·00752	0·001470
5·50	79 42	0·1788	0·0320	0·00573	0·001020
6·00	80 33	0·1642	0·0269	0·00441	0·000724
6·50	81 16	0·1518	0·0231	0·00351	0·000534
7·00	81 53	0·1412	0·0199	0·00280	0·000396
7·50	82 24	0·1323	0·0174	0·00230	0·000303
8·00	82 53	0·1239	0·0154	0·00190	0·000237
8·50	83 17	0·1169	0·0137	0·00160	0·000188
9·00	83 40	0·1103	0·0121	0·00133	0·000146
9·50	84 0	0·1045	0·0109	0·00113	0·000119
10·00	84 18	0·0993	0·0099	0·00099	0·000980

Discussion.

Mr. Berkley. Mr. GEORGE BERKLEY, President, said that he was sure it would be the pleasure of the members to accord a vote of thanks to Mr. Trotter for the instructive Paper he had presented to the Institution.

Mr. Trotter. Mr. A. P. TROTTER explained that the photometers discussed in the Paper were illumination-photometers, and that he had not dealt with the question of candle-power photometry. His photometer was still in an experimental shape, and he had thought it hardly worthy of full description in the Paper, but, as it was upon the table, he would show the way in which it was used. It weighed about 19 lbs., and, owing to the batteries being placed at one end, was somewhat awkward to carry. (Mr. Trotter then made a measurement of the illumination in the meeting-room, which gave as a result 0·9 candle-foot.) He had made a measurement some months ago with the instrument carefully standardised, and he found that 0·8 candle-foot represented the illumination in that room. Other photometers of interest were exhibited in the library, together with the very interesting radial-photometer of Mr. Dibdin, for measuring the illumination from gas- and other lamps at different angles.

Mr. Dibdin Mr. W. J. DIBDIN referred to a statement made in the Paper as to the parliamentary candle being of about as much value as the standard barley-corn. He did not altogether disagree with that, for he thought that the standard candle was a most unreliable instrument. When it was used with the greatest care, and when correction was made for the amount of light, according to the quantity of sperm consumed, there might be errors under certain conditions of as much as 20 per cent. Errors of 5, 10, and 12 per cent. were quite common. But when no correction was made for consumption, merely taking the sperm candle as a candle, there might be errors of as much as 50 per cent. The Author had taken a convenient standard of illumination, viz., the candle-foot. He almost appeared to speak of it as a new standard, but that was probably not meant. It had certainly been used about thirty years ago—first, he believed, by Mr. Sugg—the unit of illumination being taken as the value of one candle at a distance of a foot. From the description of the Author's photometer, the amount of light reflected from the cardboard screen seemed to

Mr. Dibdin.

be assumed to vary as the cosine of the angle of incidence of the light. But the Author had said that it was finally calibrated empirically, and had shown wisdom in foregoing the correction for the cosine of the angle. In 1884, Mr. Dibdin had read a Paper before the Society of Chemical Industry on some new phases in photometrical practice.[1] He then introduced for the first time the radial-photometer. He found that the amount of light falling at an angle below the horizon upon a vertical screen or wall, would be in proportion to the cosine of the angle, but that there was an altered condition of things whenever the light fell at an angle upon a photometer-disk in a vertical position, and was compared with light falling horizontally upon the disk from an opposed light. In the latter case, the disk grasped the whole of the rays, reflecting some of them back perpendicularly, while in the other case, one might assume that the amount of reflection from the disk inclined to the falling rays would be different from that placed perpendicularly. He made a series of estimations of the light, as measured with the vertical disk, and as measured with the disk so placed that the light fell at equal angles of incidence on either side. He took the mean of a large number of observations with lamps of different powers, one of 453 candle-power and one of 26 candle-power. When the rays from the burner, making an angle of 22½° below the horizon, were measured by a vertical disk, and the reading so obtained was corrected for the cosine of the angle, he found that he had a loss of light, due to reflection, of 4·4 per cent.; when the rays fell from the burner at an angle of 45°, the loss due to reflection was equal to 12 per cent.; and when the rays fell from the burner at an angle of 67°, the loss of light from reflection was no less than 69·1 per cent. So, to calculate any correction for the cosine of the angle upon the disk would be utterly fallacious, especially when more acute angles were measured. He therefore came to the conclusion that the only way in which light, falling at a different angle to that of the opposed light, could be measured, was by placing the disk in such a position that the angle of incidence was equal on each side. By doing that, the measurement of the light was obtained with perfect accuracy, and the radial-photometer exhibited that evening was designed on that principle. There was one remark in the Paper of the highest importance, namely, in reference to the character of the disk used for testing the light, especially

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[1] Journal Soc. Chem. Industry, 1884, p. 277.

Mr. Dibdin. with those of different colours. He would, if permitted, read a short extract from his Paper referred to above:—

> "The Bunsen, or greased disk, under ordinary circumstances, with lights of equal colour, is all that can be desired; but when used for testing the electric light, or gas-burners of the recuperative class, it is very unsatisfactory, and at times useless, in consequence of the great difference in tint between the light emitted from the standard and that of the burner under examination. I have, therefore, abandoned its use for these purposes, and use a modified form of the 'Leeson' or 'Star' disk. As originally designed, this disk was unsatisfactory, in consequence of the 'cockling' of the two thin papers on either side of the perforated stout paper. To such an extent was this fault found to interfere with the readings, that the Gas Referees, some time back, disallowed its use at the metropolitan gas-testing stations under their charge.
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> "Finding that the Bunsen disk did not answer all the purposes required, I modified the Star disk by pressing together the three papers, of which it is formed, with very thin starch water, and drying the moist disk under pressure. This treatment effectually prevented 'cockling,' and the use of the disk in its present form is sanctioned by the Gas Referees. The great advantage of this form of disk is that very sharp readings are readily obtained, with totally different coloured lights; red and blue lights are compared with the greatest ease, an advantage which no words of mine can enhance."

He had used that disk for all sorts and conditions of photometry, from electric arc-lamps to lights of considerably less than one candle-power. Whatever was the colour of the opposed light, the star was equally illuminated. It was a combination of the Bunsen and the shadow photometers, and lights of any colour could be readily measured with the greatest ease. With regard to gas-testing, there were two things. There was the photometer for measuring the amount of light, which had nothing whatever to do with thermometers or gas-measuring apparatus; and there were gas-meters, thermometers, barometers, and the like. People had been too much in the habit of looking upon gas-measuring apparatus as a sort of superior gas-fitter's work; but if the apparatus to which he had referred were made in glass, everybody would consider it a much more scientific thing. The apparatus was simply for measuring the volume of gas used, its temperature, and so on, and it should not be ranked as a photometer. A photometer was an instrument for ascertaining the point where two opposing lights gave equal illumination, and giving the distance between those two lights and the point. Under no circumstances ought the accessory apparatus to be classed with photometers, any more than a retort or a gas-holder should be considered as part of the photometer. The Preece photometer, which he had examined some time ago, appeared to be really nothing more nor less than the original Bunsen photometer.

There had been a good deal of misconception as to what the Bunsen photometer was. They used a Bunsen disk, and were therefore under the impression that they had a Bunsen photometer. As a matter of fact, he did not know where to put his hand upon a real Bunsen photometer, except that of Mr. Preece, which was a near approach to it. In the Bunsen photometer, a light was placed in a box, and a piece of paper at the end of the box with a grease-spot upon it. That piece of paper had an equal illumination under all circumstances on one side. The operator then moved the disk closer to, or further from, the light that was to be measured, and, at a given point, found that the disk was equally illuminated. Then he said that at a given distance the light was so and so. Then he turned the box round for another light to be measured, and repeated the operation; and said that the squares of the distances of equal illumination were so and so, and the ratio of one light to the other was so much. That was really what he understood the Preece photometer to consist of. It was what he might call an original Bunsen photometer, with a glow-lamp instead of a candle. The Author had said that the glow-lamps and the batteries now used were so much improved that they no longer resembled those in use a few years ago. He was sincerely glad to hear it, because, even under the best conditions, the light of the glow-lamp varied very much. He had recently been examining the illumination given by electric glow-lamps, and, to his surprise, even when the voltmeter and amperemeter indicated no difference in the current, he found variations of as much as even 10 per cent. in his readings compared with a standard which he knew did not vary even 1 per cent. He was certainly very much surprised to find such a remarkable fluctuation in the amount of light given by electric glow-lamps; at one time, he had hoped that they would be able to get a standard of light from them; but it was now found that all hope of that would have to be abandoned, at any rate, as far as his experience had gone. Better methods, however, might produce better results. Mr. Dibdin.

Mr. W. T. SUGG, referring to the standard of light adopted by the Author, the glow-lamp, presumed that the meaning was that the light should not be considered exactly equivalent to one candle, but sufficiently near to test street-lighting; in which there were so many things to interfere with the accuracy of the observations, that it was possible, even with the very best standard of light, that true results might not always be obtained. He had made a number of experiments with a portable photometer which Mr. Sugg.

Mr. Sugg. was carried on wheels about 3 feet from the ground. It would, of course, have been easy under those circumstances to find exactly what the result would have been on the ground. The Author, however, had thought it better to put his photometer on the ground, and the instrument appeared to Mr. Sugg to be a very ingenious one. Some good results had been obtained, but some of the lines round the lamp-posts appeared not to represent the true value of the illuminating-power in all directions. He supposed the Author had taken the value in one direction, and assumed that it was the same all the way round. It was impossible to get the same result in every direction with an arc-lamp. It would be found, whichever way the crater turned, there would be more illumination in that direction than in another. Possibly he had not understood the way in which the Author meant the figures to be read. No doubt the characteristic curves given by the Author, showing the light at different points, would be very useful in connection with the general regulation of lighting, especially if they could only get parochial authorities to look at the matter in a scientific way. The usual rule was to erect a lamp-post at any height and put a lamp upon it. It might be that the lamp-post was much too short; that did not matter, the lamp had to be placed upon it. It often happened that the lamp-posts were already fixed, and no means existed of altering them. The only case in which he had been able to feel satisfied with lighting requirements was that of the Grand Committee Room of the House of Commons. A piece of paper was given to him with some pencil-marks upon it, and his instructions were that a sufficient amount of light should be given, to enable a man with ordinary eyes to read what was written on the paper. He only had to get half-a-dozen men to read the paper, and see at what distance they held it from a standard candle. Then the problem was solved; the light required being one candle-foot. With regard to the photometer which he had exhibited, he thought it hardly needed explanation. Mr. Dibdin had already explained the difference between a photometer, as mentioned by the Author, and a photometer which had to measure the illuminating-power of gas. It was perhaps not generally known, that the testing of gas in London was the most severe of any in the world. There were twenty-three testing-stations in London, about the same number as in Paris. In London, if a company was five-tenths of a candle below the standard of sixteen candles, it was fined. The test might be made in any one of the testing-stations, and the result of three, or at most, four, testings would determine the illuminating-power for the day, at that particular point. A test might be taken at any three consecutive hours of the day, or at any three times during the twenty-four hours. In Paris the results from the twenty-three or twenty-four Arrondissements were totalled, and the average of the illuminating-power was taken. Taking the average of that number they could not well get far wrong. Still further, they took an average of a week, and then an average of three months, and if the company got below the standard during three months, they could pull it up in the next three months. The average being obtained in that way, it was not wonderful that they were able to work to within the second place of decimals of the required standard of illumination. Mr. Sugg.

Mr. Frank Wright observed that the laws governing the action of light rendered its distribution, in anything like equal intensity over the area to be lighted, a very difficult matter; but the Author had clearly pointed out the best method of procedure. He should be glad to hear what was the primary standard used by Mr. Dibdin in estimating the vagaries of the glow-lamp; as, if that could only be ascertained, they might have a means of arriving at an ideal standard of light. He did not think that any gaseous flame was likely to furnish an invariable standard. Many persons seemed to be under the impression that, given a gas of definite composition, the consumption of a definite quantity of such gas in one, the same, burner, would ensure a constant result; but such was not the case. The errors induced by the changes of density and temperature of the air-supply affected the question. The main question, however, dealt with in the Paper, was the proper amount of light for different situations in houses and streets. Taking the characteristic curve relating to the street-lamps of London, as exemplified in the Great George Street diagram, he thought that a careful study of the same should lead to a better method of illumination. What was wanted was not so much a high intensity, but a constant degree of illumination; for nothing was so trying to the eyesight as a continual change in intensity of illumination. He was pleased to find that the lighting of Whitehall compared so favourably with the electric lighting of Queen Victoria Street. Mr. Wright

Mr. W. J. Dibdin stated that the standard he used was that which he had himself introduced as the "pentane-argand," which gave a standard equal to 10 candles. It did not vary even with different pressures of gas, that was, with different heights of flame between 2½ and 4 inches; it did not matter whether it Mr. Dibdin

Mr. Dibdin. was exposed to a freezing temperature or to 90° Fahrenheit; nor was it subject to fluctuation on account of the varying height of the barometer. It would be seen, therefore, that it was a tolerably reliable standard.

Mr. Preece. Mr. W. H. PREECE expressed a hope that the distinction would be observed between the distribution and measurement of illumination, and the distribution and measurement of light—two very different subjects. They wanted to know as a rule the amount of illumination of the surface on which they wrote or read, caring nothing for the source whence the light emanated; it might be sunlight or moonlight, it might be the ancient flambeau, or it might be the candle; whether it were gas or electricity, they cared nothing—all that they wanted to know was the intensity of the illumination of the surface on which they were then reading or writing. Nearly all instruments had been devised to measure the intensity of the light source; and they worked by a comparison of two sources of light. Their present object was to determine the illumination of a surface. In 1883, he had paid a great deal of attention to the subject, and had devised a photometer which had been exhibited in one or two forms; one modified form being exhibited that evening. In 1884, he ventured to suggest a unit of illumination and to apply a name to it. His experience was that it took twenty years to introduce a unit and a name. The well-known electrical units, the ohm, the volt, and the ampere, took twenty years before they were adopted by the world at large; and he scarcely hoped that the word "lux," which he had introduced as the unit of illumination, would be generally accepted until the year 1904. But that unit of illumination was an extremely useful one. The Author had taken a step in the right direction in calling the unit a "candle-foot," but he much doubted whether the world at large was prepared to accept such a composite word as candle-foot, when it had offered to it, in a language which they were all taught, but which most of them had forgotten, the word "lux." That word had the advantage of being common to every country, and quite independent of the source. That was an enormous advantage in the application of a name to any unit. He did not know where they would be if, as units of length, they had not the mile, the naut, the fathom, the yard, the foot, the inch, the ell, and a few others. Each of those names, although they were units of length, conveyed to the mind a distinct and concrete idea. Every one who used the term foot as applied to the unit of length knew what he meant, but, if they simply spoke of a unit of length, no one would know what was meant. The same remark applied to pounds and ounces, gallons and pints. When they used a unit of measurement of any sort, it must have a name to indicate what it was, and that very name was a definition. When a name was applied to a unit, they were bound to think what it meant. If it conveyed no idea to the mind, they were obliged to enquire what it meant, and that impressed it on the mind. The Author had told them that the light in the room gave an illumination of about 0·8 lux. Mr. Preece did not think it was quite so much, judging by the difficulty he had in reading his notes at that table, although it was so sometimes. The light in that room was very variable. They had no gas-pressure gauge to tell them what the changes of pressure might be. Sometimes they might come into the room and read with the greatest ease, but at other times it would be with the greatest difficulty. He believed that was simply due to variations of pressure, which in their turn produced variations of light. In terms of that unit they were able to measure daylight; and the daylight that entered a room, reflected from a great mass of white cloud, was the softest and purest in existence, and what all artists desired to enter their studios. Bright sunlight was beyond their power of measurement, but the reflected light of a great white cloud, which was pure daylight, gave 25 luces. Moonlight, on the other hand, was a light that they read by with difficulty, and the Author had told them that bright moonlight only gave $\frac{1}{30}$ lux. He contended that, if they had a unit which enabled them, in the same language, at one moment to express the intensity of daylight and at the next the intensity of moonlight, they had two extremes, and they must have a very useful unit indeed. The great problem before engineers was, how to distribute light uniformly and evenly over the surface upon which they worked. They might have halls such as that in which they then were, and great buildings like St. Paul's Cathedral; but they wanted to be able to teach the architect how to distribute light through those buildings so as to effect their purpose properly. They had for that purpose two forms of lamp—the arc-lamp and the glow-lamp. The former gave an extremely bright, clear, and silvery light, but it was too intense for the eye to look at; the latter gave a light equivalent to that emitted by the best gas-burners. Practically, there was no difference in the light-giving capacity of a good gas-light and a good glow-lamp. The only difference between the two was that the one vitiated the air and the other did not. Whenever the

Mr. Preece.

Mr. Preece. gas was free from disturbing elements in the atmosphere, as in that room, there was very little difference between the values of gas and electricity as illuminants, except in cost. Arc-lamps and glow-lamps, in the language he was about to use, were not to be measured by the light they gave in candles, but by the light they gave in terms of the expenditure of energy. Light, from whatever source, was due to the expenditure of energy. There must be heat. The philosopher dreamed of the day when, like the glow-worm and the phosphorescent light upon the summer sea, light might be produced without the expenditure of heat, but practical men at the present moment saw no prospect of the realization of such hopes; they knew that light, from whatever source it emanated, was simply due to the expenditure of energy in the form of heat. The expenditure of energy could be measured in distinct units. The engineer was practically acquainted with the foot-pound; the electrician rather threw aside the foot-pound, and preferred to use the watt,—the watt and the foot-pound per second being closely related. The watt meant the rate of the expenditure of energy, the foot-pound the amount of work done. 550 foot-pounds per second meant a horse-power; and a watt was about three-fourths of a foot-pound per second. The arc-lamp gave its light, because energy was expended in it at a rate which produced an extremely high temperature, the highest they knew—about 6,000° Fahrenheit. They had there a candle for every half-watt expended; in other words, every watt expended in the arc-lamp would give two candles. In the glow-lamp, which was now generally used, an expenditure of 4 watts was required for one candle, so that the arc-lamp was a much more economical source of light. But the latter had the great disadvantage of being not only afflicting to the eye, but also having a tendency to give an untrue representation of colours. It had been generally supposed that the arc-lamp reproduced the colours of nature in all their purity; so it did, but the light that the arc-lamp shed upon the surface, gave an appearance that artists called a cold or chilly effect—a bluish effect, due to the intense illumination—instead of the soft daylight which was the normal appreciation of colour. That led him to the point at which he was aiming—namely, a law or a rule that would enable any one to determine how to illuminate a space, which was virtually the object sought by the Author in his Paper—to determine, first, what illumination was, and, secondly, how they could light up spaces. If they used arc-lamps for halls, for large buildings, exhibitions or railway-stations, they must arrange the light so that it should shed, uniformly over the surface to be illuminated, the amount of light that was given by ½ watt per square foot. If, for example, they wanted to know how many arc-lamps to put in an exhibition-hall, they would have to take the superficial area to be illuminated. The thing to be done was to distribute the light uniformly over the hall. As a rule, that was not necessary in the case of a railway-station, where the platforms only needed to be well illuminated. Taking an arc-lamp at a height of 25 feet, and distributing the lamps so that there should be ½ watt per square foot, the building would then be so illuminated that every one could practically see to perfection. In the case of the South Kensington Museum, for example —and he believed no place was better lighted—there were a number of beautiful little objects that required an intense light, and everything was arranged so as to have 2 watts per square foot. He might also take the case of the British Museum reading-room, or, perhaps the most successful case that he knew, the reading-room of the National Library in Dublin. He had there arranged the room with arc-lamps, and at once the matter became a grievance. The idea of lighting the reading-room of the National Library in Dublin with arc-lamps was felt to be so horrible, that a deputation from the National Society of Ireland came to London to wait upon the Chief Secretary, and it was begged that the building might not be so lighted. Mr. Preece promised faithfully that if, after three months' experience, they still desired the arc-lamps to be removed, they should be removed and glow-lamps should be substituted. At the end of three months, he announced that the arc-lamps were about to be removed, and then another deputation came and begged that they might be allowed to remain. The reason why they were so successful was, that he distributed the lamps according to the law he had mentioned, so that there was 1 watt per square foot over the surface. With regard to private houses, they all desired their rooms to be comfortable, and they wanted to have a soft uniform light in every part. That could be accomplished by so distributing the glow-lamps that there should be 1 watt per square foot of surface on the floor space. By fixing, 8 feet above the surface, a 16-candle lamp, which absorbed 64 watts, it would illuminate 64 square feet. So that, taking the floor surface of any room to be illuminated, if they divided the superficial area in square feet by 64, they ascertained the number of 16-candle lamps, fixed 8 feet high, that would distribute over all the tables and the surfaces on which they wanted to write, one lux. That was a rule which he had followed

Mr. Preece.

Mr. Preece. with a certain amount of success, in illuminating his own rooms and those of his friends. The Author had stated that he looked upon street-lamps as pilot-lights. Street-lamps were essentially for the security of the traffic. They knew very little as to the number of accidents that occurred in the streets at night; 150 deaths occurred every week in London from people being run over in the streets, and most of those accidents took place at night, when the streets were badly illuminated, and people could not see the vehicles rushing along. Robberies were also rife at night. In America, especially in New York, it had been stated that every arc-lamp saved the expense of a policeman. Street-lighting, therefore, instead of being merely pilot-lighting, was a matter of great importance in regard to security. The most important part of the Paper was that which showed how streets should be illuminated; the curves showed how they ought to distribute the lamps. One of the great lessons which the Paper taught, was that, up to the present moment, with the exception of the gas-lamps in Whitehall, they had scarcely followed any law in deciding the way in which streets should be illuminated. They wanted a better electric-lamp for the streets. The Author had shown that, even in Queen Victoria Street, which he had hoped was going to be the best lighted street in Europe, that was not the case; because the lights were too intense and their distances apart were too great. The moral that he drew from the Paper was that, for effectual and complete street-lighting, they wanted smaller arc-lamps placed closer together. There was no place in Europe where electric street-lighting was so efficient and beautiful as in Florence and Milan, where arc-lamps, fixed on guys suspended from house to house, passed over the centres of the streets, about 25 feet high and from 80 to 100 feet apart, the result being that the streets were uniformly and beautifully illuminated. He would not be satisfied until something of the same kind was done in London. It was partially done in Tottenham Court Road, but there was too much illumination in the neighbourhood of the lamp-posts and too little in the centre of the streets between the posts. Another great lesson taught in the Paper was the obstructive influence of the kind of glass used to obscure the lights, not only in the houses but in the streets. They had had in London several modes of fitting up lamps, and the several companies which held the contracts had tried various classes of glass. He had made some careful measurements with four kinds of glass, as applied to arc-lamps of the character used in the city—lamps consuming about 500 watts, and giving about 1,000 candle-power, taking the maximum intensity of the illumination. He took, as a unit, a lamp shining through clear glass, and started from that. The first glass measured was that called mediæval rippled glass, which was slightly opaque; it was by no means ugly, and it was very efficient, absorbing practically 22 per cent. of the light passing through it; another kind, called opal glass, absorbed 25 per cent.; but the favourite material, that generally known as ground glass, absorbed no less than 46 per cent. of the light. So that when they took the trouble to expend 1 HP. in an arc-lamp, to obtain about 1,000 candles, they really had no more than 600 candles, because the light was obstructed by the ground glass. With regard to his own photometer, which had been exhibited, it was an instrument which he had found of great value, enabling him to measure the intensity of illumination anywhere. It could be carried about in a portmanteau. All that was wanted was a little secondary battery well charged up. They wanted a standard source of light in laboratories. The old British candle—*quâ* candle—was a splendid thing; but the sperm candle No. 6, that gave 1-candle light when it consumed 120 grains per hour, was a myth. The substance of which the candle was made was very different from that of which it was made when the Act was passed defining it. The material manufactured in different parts of the country would give an entirely different intensity of light. A commission was sitting on the subject at the present time. Great good would be done if they could have in the laboratories an absolute standard of light, because all the rest would then follow, including his own lux. Mr. Preece.

Dr. W. E. Sumpner said that the Author had done well to call attention to the high reflecting power of diffusing surfaces, such as white paper or white-wash. The influence of the walls of a room in increasing illumination was, he thought, hardly fully appreciated. There was scarcely any kind of surface that did not reflect a certain amount of light. Even a wall that had been black-washed, as in the case of photometry rooms, reflected between 2 per cent. and 5 per cent. of the light incident upon it; and he believed that the walls of rooms, ordinary light coloured walls, reflected about 50 per cent. of the incident light. The effect of that was twofold. In the first place, if the walls of a room reflected 50 per cent. of the light, the reflecting action of the walls was to double the illumination in the room; secondly, it made the illumination all over the room much more uniform, and so diminished the shadows. At first sight, it might be thought that, if the illumination in a room were to be doubled by the reflection Dr. Sumpner.

Dr. Sumpner. of the walls, it would be necessary for the walls to throw back all the light incident upon them, but a little consideration showed that that was not necessary; it was only necessary for the walls to reflect 50 per cent. Supposing, for example, that a lamp in the room were of 100 candle-power, and that 50 per cent. of the light incident upon the walls were thrown back into the room, that half would be equivalent to another lamp of 50 candle-power. That second lamp threw out rays which were again incident on the wall, and half of that was also reflected back into the room, and that second reflection was equivalent to an extra light of 25 candle-power; and so, by successive reflections, the action of the wall was to produce an effect of an additional 100 candle-power in the room. If, therefore, the walls of a room absorbed only half the light, the illumination in the room would be doubled, and, if the wall absorbed only one-tenth of the light, the illumination would be correspondingly increased by the action of the walls. It was not at all impossible to get substances which would reflect 50 per cent. of the light. He had made a few rough experiments with different kinds of paper, and had found that white blotting-paper reflected nearly 60 per cent., and that white cartridge paper, such as that used for ordinary diagrams, reflected about the same amount. Dark yellow paint, such as that on the walls of the hall of the Institution, reflected quite 20 per cent. of the light. So that the illumination due to walls, although they might be rather dull, was quite appreciable. Just before the meeting had commenced, the Author had made measurements with the photometer on the table; first, of the illumination due to the walls and the lights; then, of the three lights, all light from the walls at the back being shaded off, so that the photometer only received the light incident from the white diagrams in front; and it was found that the light reflected from the white paper was a third of the whole light in the room. Of course, the wall covered with diagrams was brighter than the other walls, but it showed that the illumination from walls was a very important thing. In most ordinary rooms, there were white-washed ceilings, the illumination of which must also be of importance. The Author had alluded to an experiment, by means of which he deduced the reflecting-power of white paper, plaster of Paris, and so on. He thought, however, that there was an error in the calculation of reflecting-power. The Author had found that the reflecting power of white paper, white-wash, &c., was about 85 per cent.; but Dr. Sumpner did not think it was so much. The Author had taken merely the reflecting-power in one direction. The light sent out by a diffusing surface was greatest in the normal direction, and gradually diminished as the angle of incidence increased; and, if the Author had taken the mean candle-power in different directions, sent out by the reflecting surface, he would have found that the whole amount of light thrown back by the white paper, instead of being 85 per cent. of the incident light, was only about 47 per cent. If they could get walls that would reflect 85 per cent. of the incident light, absorbing only 15 per cent., such a room would only require one-seventh of the candle-power to produce any given illumination, that a room of the same size would need if its walls were painted black. Dr. Sumpner.

Mr. Bailey. Mr. F. Bailey remarked that hitherto they had been accustomed to put up a lamp where they were told, or where it had been suggested, in order to see how it looked; but it was obvious that, in future, they would not only be able to benefit by the experience of others, but would be able to tabulate results in such a way as to be able to pre-determine the amount of illumination to be given in any proposed area. In all other branches of engineering, they learned from the experience of those who had worked at the subject all their lives. That was of special importance to the younger members of the profession, and they would therefore expect to find, in all future engineering pocket-books, very valuable data derived from places already lighted either by gas, electricity, or other illuminants. He would suggest that more information should be given as to the state of the atmosphere, when measurements of the kind described were taken. It might be foggy or humid. It must have been noticed how illumination, particularly in London, was improved after a shower of rain. He did not quite see anything in the Paper, enabling them to predetermine the absolute illumination of a street which was flanked by high buildings of tolerable reflecting power. Of course, they would expect to lose a great deal by the dingy buildings seen in most thoroughfares. He confessed that he felt difficulty at first in appreciating the quality of the Paper, but it had flashed upon him all at once, in comparing the subject treated with that of the steam-engine indicator. They had always been able to speak definitely of the initial candle-power of the source of illumination, just as they used to speak of the initial steam-pressure at the boiler or the cylinder; but, until the Watt indicator came, they had no means of ascertaining the average pressure throughout the stroke. The little instrument now exhibited did exactly for the electrical engineer what the Watt indicator had done for the steam-engine engineer, and they hoped

Mr. Bailey. not only to see it universally adopted, but also to see the results recorded for the benefit of their successors.

Mr. Deacon. Mr. G. F. DEACON mentioned that for a considerable time, from the year 1871, he had been responsible for the public illumination of Liverpool, and in 1878, the year of the Paris Exhibition, when the Jablochkoff candles were first brought out, much interest was taken in Liverpool in the new illuminant. Many persons were making photometrical experiments on their own account, all measuring the illuminating-power of the different illuminants in the horizontal plane and comparing it, without any other consideration than that of cost, with gas. He was then asked to go to Paris and report upon the illumination of the Boulevards. He did so, and his report had the effect of causing the Corporation to defer the question of electric lighting, nearly to the present time. He thought that had been a very good thing for the Corporation, though, perhaps, if the matter had been taken up then, there might have been more failures, and more discoveries consequent thereupon, than there had been. It was stated, even in those early days of electric street-illumination, that they could get as much candle-power by the Jablochkoff candle, for the same money, as could be obtained by gas. That at once, he saw, was impossible; but on reducing the question to facts and figures, it appeared to be even further from possibility than he had at first anticipated. In those days there were no Trotter candle-feet, nor Preece luces, nor any such luxuries; but, of course, he adopted the same method without having the name of the unit, and he measured the illuminating-power, not in the horizontal plane, and at a constant distance from the illuminant, but over the surface to be illuminated. It was the Boulevard de l'Opera that was so particularly well illuminated, and he took that as an example, and found that the cost was something like six times the cost of Liverpool gas, producing an equal illumination, and twenty-one times the cost of the Liverpool gas which would, under ordinary circumstances, be consumed in the illumination of an equal area; the reason being that there was a considerable difference in the cost per unit of light, and an enormously greater difference due to the diminution in the intensity of the light being inversely in proportion to the square of the distance from it. Mr. Preece had referred to the ceiling of the Public Library in Dublin. Mr. Deacon ventured to think that the public library in Liverpool, the Picton Reading-Room, was, when the ceiling was kept properly white-washed, one of the best illuminated rooms in the kingdom, if not in the world. It was a circular room, 100 feet in diameter, with a domed ceiling. Being at the time full of the question of illumination of the tables and floors, he had put in the centre of the room three arc-lights—back to back—and he believed they were the first arc-lights ever used for such a purpose in such a position. Under those he had put an opal chalice, 12 feet in diameter (which they had to go to Berlin for), resting on an ornamental vase. He had then white-washed the dome of the ceiling, and the effect was excellent. The absolute amount of light was nearly uniform over the whole surface of the tables, but he did not remember exactly what it was. He entirely agreed with Mr. Preece as to the great success of the illumination of Florence and Milan, and he might add Genoa, which he thought almost better than either of the others. Mr. Deacon.

Mr. W. H. Y. Webber said that there had been a great deal of uncertainty about the distribution of light over streets, and, as a consequence, a great deal of charlatanism. It would be much fairer if the measurement of arc-lighting especially, were expressed commercially, as well as in scientific assemblies, by the consumption of energy in watts. The Author had properly treated the subject on the basis of the general laws of optics; and it was a significant circumstance that he had found the illumination in Whitehall practically as good as, if not better than, the arc-lighting in Queen Victoria Street. The highest illuminating-power of any lamp in Whitehall was 270 candles; and, even accepting Mr. Preece's statement, the light given by the arc-lamps in Queen Victoria Street was equal to between 600 and 750 candles. That raised the question once more, whether the arc-lamp was best for outdoor and street use. He did not think that it was. Irrespective of the question of origin, he thought that any light of such intense power as that, required very careful handling to prevent a spotty effect. The power which a light should have depended to a great extent upon the width of the street; and there would be few places where the power of 500 candles would be a convenient quantity to use. The series of articles upon lighting by himself, to which allusion had been made in the Paper, were strictly elementary, and had not dealt with the question in the elaborate manner adopted by the Author. But he ventured to think that no very abstruse treatment of the subject was really necessary, to show how the lighting of streets and interiors might be rationally computed, with sufficient accuracy for practical purposes. The Author had admitted that Mr. Webber had suggested, in reference to street-lighting, the necessity for determining the ratio between the brightest and dimmest parts of the thoroughfare. That Mr. Webber.

Mr. Webber. had not been usually done. Of course, the ratio did not show the absolute amount of the illumination, but that could be computed. He wished particularly to draw attention to the formula given by the Author. He thoroughly agreed with the statement that, "by the practical application of the cosine law, the illumination which will be produced by any given arrangement of lights may be determined." Upon that basis, he thought they might let the matter rest, and he was a little afraid that with the extremely laborious photometric work of the Author, its essential simplicity might be overlaid. The Author had given the data upon which to proceed, and his calculations and formulas would be sufficient, because the errors of calculation would not exceed the errors due to the use of what must necessarily be an imperfect photometer, used in circumstances unfavourable to exact observation. He also gathered that the Author did not think highly of the rule which Mr. Webber had mentioned as to the best height for a vertical light illuminating a flat surface. The rule was,—the maximum useful command of an elevated light over a horizontal plane, is represented by a circle of radius $\sqrt{2}$, the height of the lamp being unity. He had used that formula for arriving at an equally diffused illumination for interiors, which was a different problem altogether from that of exteriors. They could never afford to have equal distribution outside; but indoors there should not be any perceptible maximum or minimum.

Mr. Kapp. Mr. G. Kapp drew attention to a point in the Paper which appeared to him to be of considerable importance, namely, the great reflecting power of a white surface, not a mirror. About two years ago, he went through a factory in Berlin, which had been newly fitted with electric light. The operations which were performed were of a rather delicate nature, fine wheelwork and other mechanician's work, and great difficulty had been experienced in finding a suitable light. The ordinary arc-light would not do, because it cast too strong a shadow, and, in turning arbors and axles, and milling toothed wheels, a uniformly diffused light was required. Glow-lamps, which might have fulfilled this condition, were too much exposed to breakages, from chips flying about, and from the careless handling which workmen were accustomed to bestow upon the ordinary gas-burner. The solution which the manager of the shop had found, was to put the arc-lights into big funnel-shaped covers, white-washed inside, and to hang them up 8 feet from the floor, just high enough for a man carrying anything on his shoulder to pass under without knocking against them. The ceilings were kept white-washed, and the effect of

Mr. Kapp.

the lighting was excellent. The arc could not be seen, being entirely hidden by the funnel, but the room was filled with a very soft diffused light, so that the delicate machine-work could be carried on by night as well as by day. It had struck him that it was an excellent way of lighting, although rather wasteful. Having read the Paper, he found that the manager of the Berlin factory had hit upon a really good plan of lighting his workshop; and he mentioned the matter in case any members should be desirous of lighting workshops by arc-lights. With reference to the rule given by Mr. Preece, as to the amount of power to be spent in lighting certain spaces, he confessed that he could not see why, when they wanted to light well by arc-lamps, they should spend 1 watt per square foot (Mr. Preece: Half a watt). The amount stated was ½ watt for a railway station, 1 watt for a reading-room, and 2 watts for a museum; he therefore took 1 watt per square foot as an average for good lighting by arc-lights. He would have put it down as about ¼ watt. It was almost impossible to lay down a hard-and-fast rule of that kind. Any one who had had to plan out installations must have gone through certain experiences. He might confess that he had himself planned installations with 16-candle-power lamps, and had afterwards to put in 32-candle-power lamps; simply through having omitted to take into consideration not only the colour, but the tone of the colour of the walls and the furniture of the room. He made a practice of putting in wires suitable for larger lamps, if doubt existed as to the effect of wall decorations. A year ago he had to advise the owner of a large country house with regard to lighting. There were two rooms, each about 100 feet long by 30 feet wide. One room was a museum, used as a ball room, filled with cases containing specimens of birds, and painted white inside. The other was a picture gallery, wainscotted high up with dark oak. The museum took ¾ watt per square foot, and it was then brilliantly lighted. The other room, with the old wainscot, required more than 2 watts per square foot.

Mr. Foster.

Mr. W. Foster observed, with reference to the much-abused candle, that he had lately asked Mr. Harcourt whether the sperm of the standard candle was very seriously deteriorated, and the reply was, "I do not think so in the least." As Mr. Harcourt was interested in giving something which would be much more reliable as a standard, he thought it was not right that Mr. Preece's remark, coming from such an authority, should pass without qualification. It was very easy, if a thing were not acting quite as it should do, to complain about the standard; but

Mr. Foster. there were many trivial complaints made under this head. His own inquiry had been with a view of working out something as to the relation between the sperm and the light which it produced. Another point referred to by Mr. Preece ought to be noticed,—that there was no essential difference between lights of a particular description—gas-, arc-, or glow-lamps. He believed that incandescent lamps had been introduced (he had used them in his own lecture-room) in one large establishment in London, and had been discarded, simply in consequence of the quality of the light. The physiological action had been such (he did not know the reason) that the workmen had preferred to go back to the old-fashioned form of light.

Mr. Trotter. Mr. TROTTER, in reply, said that Mr. Dibdin had suggested that the candle-foot was not altogether a new name, having been used by Mr. Sugg thirty years ago. He was interested to learn that such was the case, but it was a very obvious unit, and for that reason perhaps a useful one. Mr. Preece's word "lux" was, he believed, originally put forward as the equivalent of the Carcel-metre, and it was about twelve per cent. greater than a candle-foot. But if Mr. Preece wished to denominate the candle-foot by the word "lux," no doubt it would be quite as useful. He had been told that "candle-foot" was a very erroneous name. He had discussed the subject with Mr. Swinburne, who had told him that it was utterly wrong and misleading, because a foot-pound implied the product of a foot into a pound; and a candle-foot might suggest the product of a candle into a foot. Every one knew that light varied inversely as the square of the distance; and, obviously, the foot was a divisor and not a multiplier. But the candle-foot as a unit had been used by many persons without knowing it, just as Mr. Jourdain had been speaking prose all his life without knowing it. Professor Henry Robinson, in his description of the lighting in Tottenham Court Road, had used the unit without giving it the name; and the same thing might be said with regard to the interesting articles by Mr. Webber. The advantages of its use were that it was self-explanatory, an important matter in units, and the English language only was employed. Mr. Sugg had asked about the calibration of the photometer. He might explain that it was experimentally calibrated. The dial was calibrated step by step all the way round; it was rather a tedious process, and was carried out with a paraffin-lamp which had been compared for half-an-hour with a standard candle. Mr. Dibdin had referred to the Leeson disk. He had brought a specimen of the Leeson star-disk, which

Mr. Trotter.

was upon the table. It was an excellent screen for photometry. But as it was usual to have a 10 candle-power Argand burner, or something equivalent, at a distance of about 50 inches from the screen, there was a very powerful illumination, and far more than was obtained in street-lighting. He had had in street-lighting often to go down to 0·05 and 0·025 candle-foot, and in that case the Leeson star-disk was practically opaque, and quite useless for the work. Reference had also been made to the variation of the glow-lamp as used for a standard. He would not depend upon the glow-lamp as a standard, unless he could depend upon the source of the electric current. One could depend for many hours upon the constant pressure of a secondary battery. With a battery which was supposed to give an output for nine hours, one could rely with certainty upon it at all events for a quarter of an hour. The whole of his measurements on a single evening, giving ten seconds to each, would not extend over that period. He could not recommend the glow-lamp as a standard, because the light varied as about the 5·2 power of the current. Any inaccuracy in the reading of the current was therefore enormously magnified in the candle-power. Mr. Sugg had supposed that Mr. Trotter had taken the value in one direction, and had assumed that it was the same all the way round. The contour lines in *Figs. 36* and *37* were, he admitted, to some extent assumed; but in the case of the illumination curves such as *Figs. 39*, *40*, *41*, *37*, *33*, the whole of the observations which were made actually in the streets were recorded as dots, and only a single one had been suppressed; the others gave the actual readings, and the way they lay upon the curve gave a fair idea of accuracy obtainable with the photometer. He had hoped that some one would have taken part in the discussion, who was responsible for planting the lamp-posts in the street. He feared that those whose duty that was, did not recognise the responsibility which devolved upon them. Mr. Sugg had had lamp-posts given to him of a fixed height, and had been told to plant lamps at the top. That would account for the hap-hazard way in which the lighting of streets had been carried out. It was only when the proper ratio between the height of the lamps and their distance apart, had been properly considered, that an equal and good illumination could be expected. It appeared that the best result to be obtained was, after all, to go round and find a street which appeared to be well lighted, to analyse the illumination-curves in it, and then try and follow that out in practice. He admitted that he had perhaps gone rather too far in

Mr. Trotter. the Paper with the mathematics of the subject. His only excuse was that the subject was new, that he did not know where the calculations would lead to, and that he had thought it better to work them out and investigate the matter to the end. But coming back to the common sense view of the problem, it seemed, judging from the characteristic curves given of actual examples, and comparing them with the calculated characteristic curves in *Fig.* 22, that if one could place lamps at a distance apart equal to four times the height, there would not be any serious spottiness. If it were assumed that in a well-lighted street the lamps should be placed at distances apart equal to four times the height, also that the minimum illumination of Whitehall, 0·05, was fair, and that for a better light 0·08 or 0·1 might be taken, then the maximum illumination could be determined merely by the height of the lamps, and it would be found to be considerably less than in Whitehall or in Queen Victoria Street.

Some remarks had been made by Mr. Preece about arc-lamps being offensive to the eye, both in regard to colour and intensity. Colour was to some extent a question of habit. They had been accustomed to a yellow light at night, and a whiter light being introduced, appeared to be blue. The Americans did not call the arc-lamps blue at all. When they had been accustomed to them the imaginary blueness rapidly disappeared. With regard to intensity, it must be admitted that at Cornhill and other places the light was more than was wanted. That would be cured by placing the lamps at a height of about one-fourth of their present distance apart; that would secure the minimum illumination wanted, and the maximum would be much less. The watt per square foot was an interesting result, but he did not think that it was a safe guide. It was interesting to make deductions after one had examined a case of illumination, but, as Mr. Kapp had shown, it would be unsafe to base future lighting upon such a rule. In speaking of street-lighting as beacon lighting, he was alluding to the most feeble attempts at street-lighting that could be found. In driving along Piccadilly, for example, one could hardly see anything on the surface of the street. What one did see was the carriages as dark masses of shadow, rather than the carriages visibly illuminated. On a wet night one could see better because one saw a black mass against the reflecting puddles. It was hardly more than piloting, but that was an immense stride from darkness. If they could afford to have real illumination, by all means let them have it. He could not agree with Mr. Preece that smaller lamps closer together would be better. Ten years ago they had an experiment in lighting opposite the Mansion House with high Siemens lamps. He did not know what the practical difficulties were with those high lamps, but he had that day seen a man cleaning a lamp in Queen Victoria Street. He had a short ladder and the post was fitted with little iron steps to go up. The man had a band around his waist and appeared quite comfortable, and the work could be done as safely if the lamp-post were three times as high as it was at present. At Milan, a string of lamps from house to house might not only be permitted but enforced, but every Englishman's house was his castle, and there might be serious expenses for way-leave, and many difficulties would probably be raised in attaching wires to houses. It was true that it was done at Bradford. The inhabitants were so much in favour of the electrical tramways, with which experiments were in progress, in place of the noisy, dirty, steam-trams, that they willingly placed the walls of their houses at the disposal of Mr. Holroyd Smith, who had attached wires to them. Whether that would be done when the vestry came round to make requisitions for such facilities in the streets of London, he ventured to doubt. He should like to see some more careful experiments made upon the obstructive power of glass. He rather questioned the suggestion which Mr. Preece had made as to ground glass absorbing 46 per cent. It was true that, by taking a light in front of a photometer, and then placing a screen of ground glass between, and trying to measure it, there was a serious loss. Why was that? The light passing from the candle to the photometer was intercepted by the ground glass, some was obstructed, and a large portion was thrown off in all directions. That should be taken into account. If both diffusion and obstruction were included in the 46 per cent., it should not all be put down to obstruction alone. With a ground-glass globe the whole of the light in all directions was obstructed, and at the same time it was diffused in all directions, so there would be no error. He was obliged for the interesting remarks of Dr. Sumpner about reflecting-power, and for the correction of an error in the calculation on page 135; Mr. Trotter had omitted to consider the mean candle-power in all directions. As to the statement that 50 per cent. of the light was reflected from a white wall, and that that was equal to half the candle-power, and so on, he thought that even a greater amount of light might be reflected than that, because there would be a certain amount of selective reflection, in the same way as there was selective transmission. If a piece of red glass would cut off half the light, and another piece would cut off less, the light **Mr. Trotter.**

Mr. Trotter. which had gone through one piece of glass would have a greater chance of getting through the next piece. So with selective reflection. Light reflected from one reflector was more easily reflected from another reflector of the same kind.

Some questions had been asked by Mr. Bailey about atmospheric conditions. There were a great many obstacles in street-work with the photometer. There were the obstacles occasioned by moonlight. He could only go out on one moonlight night when it was perfectly clear. Then, besides the moonshine, there was fog, and mud, to say nothing of the meetings of scientific societies; he had always avoided foggy nights, in fact, there was about only one evening in a fortnight on which it was possible to go out. He could not find any distinct traces of reflection from the sides of buildings. The contour-lines should have shown it, but he did not think that it was perceptible. With regard to the relative lights in Queen Victoria Street and Whitehall, he might mention that the scales of *Figs. 36* and *37* were the same. There were only three lamps in Queen Victoria Street; but there were no less than twelve in Whitehall; the area was about double. The greater number of lamps necessitated a larger first cost. If the lamps in Queen Victoria Street had been higher but without change in candle-power, the illumination would have been much more distributed. And in Whitehall, if fewer, but taller and more powerful, lamps had been used, the illumination would have been as good as at present, but at very much less expense. *Fig. 23* had been specially drawn with reference to Mr. Webber's remarks in his articles about the ratio of the brightest and dullest lights. From this diagram, it would be seen that, if lamps were set at a distance apart equal to four times the height, the minimum illumination was about 0·22 of the illumination of one lamp, and the maximum about 1·1 of the same.

Correspondence.

Mr. Boulnois. Mr. H. PERCY BOULNOIS felt indebted to the Author for his efficient handling of what he might term a new line of thought in connection with artificial illumination. To him the subject was of great interest, as he was primarily responsible for the public-lighting of the City of Liverpool, which contained about 240 miles of streets in addition to about 2,000 courts and passages, and was lighted by 10,677 ordinary and 553 high-power gas-lamps. Since 1880, street-lighting by gas had made great

Mr. Boulnois.

progress, owing, in a large measure, to the introduction of a vigorous rival in the form of electric light. Great improvements had been effected, and gas might be said to have creditably maintained its position as an illuminant. There was, however, little doubt that the arc-system of street electric-lighting had become practicable, and would have to be considered. In this connection the Author's Paper, filled as it was with the most valuable data on the subject, could not fail to be of service to all concerned with street-lighting.

The suggestion to measure light as a quantity rather than as an intensity was clearly a good one; and the simplification of the means would ensure future investigation being carried out on these lines. In the past it had been the custom, in connection with street-lighting, to calculate the light on any point of the road-surface, by finding the candle-power from all the adjacent contributing lamps up to the third or fourth place of decimals; but the results had, of course, only been comparative, and at times very misleading, owing to local conditions affecting them. A method of photometry such as that described, permitting of the instantaneous measurement of the total illumination, in any position, by an apparatus that could be carried in the hand, would be a great boon to those who were practically engaged in street-lighting investigations; and, if such apparatus were reliable, it could not fail to come into immediate and general use. It seemed doubtful whether, in the case of street-lighting, the Author's object, viz., "to enable engineers to predetermine, specify for, and provide, a definite illumination," would be fully attained. Streets were not as a rule straight for any great length, nor of uniform width; the abutting buildings varied in height and reflecting-power, and the corners of streets, which were fixed positions for lamps, were not at equal distances apart. This made it difficult to subdivide the intervening spaces uniformly, and it was clear that, to adopt columns of varying heights on the side walks, to meet this latter difficulty, would be out of the question, since there was the appearance by day as well as the effect by night to be considered. With gas-lamps there was a further difficulty in the blackening of the glass—a single night's burning in the winter months often resulting in a diminution of the light of between 10 and 15 per cent. Thus the number of inconstant factors were sufficient to render the specification of anything beyond an approximate or minimum illumination impracticable. As an illustration of this difficulty, the lighting of Lime Street,

Mr. Boulnois. Liverpool, might be quoted. Lime Street was one of the most important thoroughfares in that city, and the Lighting Committee decided to light it in 1883 on the most improved system. Arrangements were made for the introduction of a new type of column, lamp, and burner, with the object of lighting the street in such a way as to render the reading of ordinary newspaper-type practicable throughout its length. It was decided that the minimum light on the road surface should not be less than 0·25 candle-foot, and the greatest uniformity was aimed at. Before proceeding with the work, plans were prepared showing the illumination at the points of least light with the lamps in different positions; but it was found that, although every care was used, in consequence of the difficulties mentioned, there were variations in the minima of the light of between 0·537 and 0·250 candle-foot; and although this appeared to be a great difference on paper, it was scarcely noticeable in the street. The figures referred to the net calculable illumination, and, if measured actually by the Author's method, would no doubt be shown to be much higher.

The data referring to electric-lighting were of great importance, demonstrating as they did the extreme inconstancy of this form of illumination. The characteristic curves shown in *Fig. 42* demonstrated that, in the case of Queen Victoria Street, while the minimum illumination was constant, the maximum varied between 0·27 and 0·72 candle-foot, the variation being apparently entirely due to the varying intensity of the arc-lights. That would be a very serious drawback in street-lighting operations; and, further, the immense difference between the points of maximum and minimum illumination seemed to be arguments against the concentration of light beyond certain moderate limits. Indeed, the curves showed that Whitehall, with its gas-lamps of between 90 and 270 candle-power, was considerably better lighted than Queen Victoria Street with electric arc-lamps of, probably, 2,000 nominal candle-power. The light for half of the distance between the lamps in Whitehall was actually superior to that of Queen Victoria Street; and throughout its length, judging from the curves, the constancy and uniformity of the lighting was greatly superior to that of Queen Victoria Street. The visual effect of street-lighting was largely comparative, and uniformity was therefore the first consideration. A patchy system could not be good. Graphically shown, the curve which most nearly approximated to the horizontal was the best, and that being so, the lesson taught by the characteristic curves appeared to be, that lamps of moderate power, fixed at moderate distances apart, were the best for effective street-lighting. Mr. Boulnois.

There were two points upon which the Author's opinion would be of value: First, with regard to the glow-lamp as a standard light for the measurement of street-illumination, it was important to know whether the Author had experienced difficulty arising from the variation of the illuminating power with the current, and, if so, how he had dealt with it. The second point was with reference to the measurement of electric light. The Author had had great experience of the difficulties connected with it, and no doubt with that of maintaining it at a uniform intensity. It would be of considerable advantage if he would state whether he considered it practicable, upon entering into a contract with an Electric-Light Company, to specify a minimum illumination—the light to be measured, in a fixed position in relation to the lamps, with the photometer that he had exhibited during the reading of his Paper.

Mr. Wybauw. Mr. WYBAUW, of Brussels, desired to draw attention to a very general error committed in the consideration of the illumination of a given place. It was not important in practice to know the illumination of any portion of a horizontal surface. The useful effect which a source of illumination could produce at the place under consideration should be ascertained. Particular data, such as horizontality of the surface, should therefore not be introduced into the calculations. It was desirable to assume any body whatever, having any kinds of faces—horizontal, vertical, or inclined—in the given position; better still, a spherical material point. "Just as rainfall is independent of the nature of the soil," to use the Author's simile, the useful effect of the illumination produced by a ray of light should be considered as quite independent of the bodies or surfaces upon which it fell. To deal exclusively with the useful effects produced upon the horizontal faces of bodies, and to neglect those upon the vertical or inclined faces, was to commit an obvious error. It was the sum of all those effects which constituted the real value of the illumination furnished by the source of light. Apropos of this matter, he would take the liberty of quoting from a Paper read by himself before the Société belge d'Electriciens:—[1]

"The illumination of a material surface is the outcome of the result produced by lighting, rendering perceptible to our senses the forms of the bodies comprised in the space under consideration. This result must not, in my opinion, be

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[1] Bulletin de la Société belge d'Electriciens, July 1889, pp. 388, 389 and 400.

Mr. Wybauw. measured by the sum of the light intercepted by an ideal geometrical surface substituted for a real material surface.

"Whatever may be the direction in which light travels, if at every point of a place it renders the same service as at every other point, I say that the illuminations are equivalent; and, taking my stand upon practical issues, it is, in my opinion, upon this principle that the illumination of stations, public places, &c., may be determined. I do not say that all forms of illumination are equally good and convenient. In the case of a place traversed by persons and vehicles, where the shadows cast have to be considered, or where the light may perchance prove troublesome to the eyes, &c.; the illumination will only be convenient in so far as the obliquity of the rays of light does not exceed a certain limit. But, below that limit, the oblique rays are quite as valuable for illuminating purposes as the vertical rays, and often more so. Their obliquity, measured by the angle made with the horizon, must not be regarded as diminishing their useful value—the illumination that they produce in the ratio 1 : sin α. Their useful effect, the real result of the illumination, does not vary according to this ratio.

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"Calculating according to the customary method, a source of light situated 5 metres above the ground gives an illumination of $\frac{1}{50}$ carcel-metre at a point A situated 13·5 metres distant from the vertical through the source. The same source will give the same illumination at another point B situated 15·16 metres from the vertical, if the height be increased to 10·65 metres. It is obvious that this is not in accordance with fact. It is, however, absolutely in accordance with the theory of the dependence of the intensity of illumination upon the sine of the angle of incidence on the horizontal plane. I do not consider that, at a distance of 15·16 metres from the foot of the vertical through a source of light, the intensity of the illumination produced by it can ever be equal to that at 13·5 metres, however high the source be raised. It is always less.

"I am quite prepared to be told that similar ideal plane surfaces at A and B will exhibit equality of illumination. But, in order that such may be the case, the surface must be horizontal; it will not obtain in any other direction. Illumination is thus not regarded in the general sense which I attach to it, and which must, in practice, be attributed to it. For the illuminations to be equivalent, we must, in my opinion, be able to read, work, or examine objects at B with the same ease as at A; which is not the case in the circumstances assumed."

Mr. Trotter. Mr. A. P. Trotter, in reply to the correspondence, observed that the minima of 0·537 to 0·250 candle-foot, found by Mr. Boulnois at Liverpool, if the unit of illumination was that used in the Paper, showed remarkably brilliant lighting—better than anything in London. The maximum in Whitehall Place was only just equal to the higher of these values. The glow-lamp was not recommended as anything but a secondary standard, and was only used on account of its portability and freedom from flickering. To ensure constancy he would not trust to the measurement of current, but to a good secondary battery. With such a battery the current would perhaps fall **Mr. Trotter.** 1 per cent. after 8 or 10 hours' work. During a quarter-of-an-hour it might be relied on as constant within 0·20 or 0·25 per cent. The light (assuming the sixth-power law) would vary 1·2 or 1·3 per cent. This might be neglected, as within the limits of error of observation. He seldom used a battery for more than a quarter-of-an-hour in one evening. Ten seconds was enough time for each reading, and this would allow for ninety readings. He was abandoning the glow-lamp for an oil-lamp and Methven screen in a photometer now in course of construction.

It would be quite practicable to enter into a contract for street-lighting with a specified minimum, but he was not aware of any precedent for that course. Electric-Supply Companies in this country rarely if ever took responsibility for the quality or amount of light, but merely supplied electrical energy. The choice of a good arc-lamp, with suitable lantern and carbons, was no more difficult than the selection of a good gas-lamp and burner; there was, in fact, smaller choice in really good electrical apparatus. The steadiness depended greatly upon careful cleaning and trimming. If this were undertaken by the Supply Company it would be fair to hold them responsible for a minimum illumination, which might be measured by any simple illumination-photometer.

The Author had previously consulted Mr. Wybauw's Paper in the "Bulletin de la Société belge d'Electriciens," but ventured to differ from the view that any kind of surface might be considered as usefully as a horizontal plane. At the same time he admitted that other cases could not be neglected, and he had dealt with them in the section entitled "General Cases of Distribution." Fig. 11 in that section was very instructive in this relation. The maximum illumination at any point would be that upon a plane directly opposite to the light. The law of illumination on such a surface was shown by the curve marked $\cos^2 \theta$. At distances greater than the height of the lamp above the plane, the minimum illumination was on a horizontal surface, and this was shown by the curve marked $\cos^3 \theta$. A vertical surface was illuminated between these limits, as shown by the curve marked $\cos^2 \theta \times \sin \theta$. At these distances the three curves ran fairly together, and he had taken the lowest one. At less distances great differences were found, but these lay in a comparatively small area, in street-work. On the whole, therefore, he thought that the $\cos^3 \theta$ curve, in other words, the horizontal plane, was the best to consider. If the curves of illumination which were given in the Paper were

Mr. Trotter. re-drawn to suit the $\cos^2 \theta$ law, they would not be materially altered in form.

17 May, 1892.

GEORGE BERKLEY, President,
in the Chair.

The discussion of Mr. A. P. Trotter's Paper entitled "The Distribution and Measurement of Illumination" occupied the evening.

24 May, 1892.

GEORGE BERKLEY, President,
in the Chair.

It was announced that the following Associate Member had been transferred to the class of

Member.

Orton Gastrell Smart.

Also that the following Candidates had been admitted as

Students.

Humfrey Alleyne Carte.
Charles Arthur Richards Farrell, B.Sc.
Alfred John Jenkins.
Edward Livingstone Joselin.
Robert Sinclair Kennedy.
George Napier.
John Archibald Polwhele.
Alexander Gordon Russell, A.K.C.
John Charles Taylor.
Hubert Dickenson Talboys Wheeler.

The following Candidates were balloted for and duly elected as

Members.

James Eustace Berkley.
George Streatfeild Morley.

Associate Members.

Richard William Allen.
Francis Philip Anderson.
Robert Frame Anderson.
James Benjamin Ball, Stud. Inst. C.E.
Charles Frederick Bamford.
John Benjamin Body, Stud. Inst. C.E.
Henry Currey Bowdage.
Charles Robert Brady, Stud. Inst. C.E.
Thomas Farquharson, B.Sc.
Charles Frederick Vernon Ford, Stud. Inst. C.E.
John George Garthwaite.
William Leigh Hamilton.
Maximilian Hector.
Alfred James, M.A.
Ernest Lupton.
Donald Marsh McClure.
George Champion McDonald, Stud. Inst. C.E.
Percy Walter Maddock.
Edward Howis Marston.
Charles Mathew.
Bakhshi Ram Singh.
Tom Graves Smith.
James Stewart, Jun.
Thomas Ward.
Frank Lionel Williams.

(*Paper No. 2630.*)

"On the Measurement of High Temperatures."

By Professor WILLIAM CHANDLER ROBERTS-AUSTEN, C.B., F.R.S.

THE importance of studying the varied metallurgical problems connected with the composition and structure of metals and their alloys, is becoming daily more evident; and, as this Institution has devoted attention to the consideration of metallurgical questions, it is hoped that a review of the present state of knowledge respecting the measurement of high temperatures may prove useful.

HISTORICAL.

The Author has elsewhere pointed out[1] that, notwithstanding the importance attached by early experimenters to the action of heat on metals, they had but little definite information respecting the relative degrees of intensity of heat; and their views were not inadequately expressed in the eighth century by Geber, who stated that great difficulties arose in conducting operations with the aid of heat, because heat cannot be measured, "*sed quoniam non est res ignis, quæ mensuari possit.*"[2] The name of Josiah Wedgewood is always associated with the early attempts to provide a practical method of pyrometry; but, although he wrote a thousand years after Geber, he seems to have merely changed the language of the latter, "heat cannot be measured," into a lament that there were no trustworthy instruments for effecting the measurement of "the higher degrees of heat, from a red heat up to the strongest that vessels made of clay can support."[3] He therefore devised a pyrometer, which depended on the contraction that clay experiences when strongly heated. It is not necessary to give a history of pyrometry in this place; the Author would merely point out that Wedgewood demonstrated the necessity for the accurate measurement of high temperatures, and that, from his time, the invention of more or less suitable instruments has proceeded rapidly.

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[1] Lecture at the Royal Institution. "Nature," vol. 45, 1892, p. 534.

[2] From the edition of his "Summa Perfectionis Magisterii," published in Venice, 1542, p. 28.

[3] Phil. Trans. Royal Soc., vol. lxxii. 1782, p. 305.

In the long interval between the work of Wedgewood and that of the late Sir William Siemens, such pyrometric appliances as were actually in industrial use depended mainly on what is known as the "method of mixtures,"—that is, upon the employment of a body, the specific heat of which was known, to transfer or carry heat from a furnace, or source of heat, to a measured volume of water, the rise in temperature of which was indicated by an ordinary thermometer. Pyrometers depending on the expansion of metallic strips or rods are also employed; but they may all be set aside with the general statement that, although they are useful in affording rough approximate measurements, they are useless for accurate pyrometry. It may be well to add that a noteworthy advance in thermometry has recently been made in Professor Ramsay's laboratory at University College, by Messrs. Baly and Chorley, who employ the fluid alloy of sodium and potassium, instead of the mercury of the ordinary thermometer; and, as temperatures of 600° Centigrade may thus be measured by thermometers of hard glass, further details of their experiments will be looked for with much interest.

Modern Work.

A new era in the measurement of heat began with the work of Sir William Siemens. He showed that electrical resistance might be used practically in pyrometry. *Fig. 1* gives a general view of his apparatus, and its nature is explained by the accompanying diagram, *Fig. 2*. A divided current passes from the battery B to a platinum wire C (coiled round a clay cylinder), and to a resistance-coil R. At the ordinary temperature, the resistance of the platinum coil is balanced by the standard resistance R, and an equal current will flow through each. If, however, the platinum coil C be heated, its resistance will be increased, and this increase of resistance can be measured in various ways. Siemens adopted for use in works, a small voltameter, shown at A, *Fig. 1*; the current sent through the platinum coil *c* was of sufficient strength to decompose acidulated water, and the difference in the amount of water decomposed by that portion of the current which passed through the heated coil, as compared with that decomposed by the current transmitted through the standard resistance at R, *Fig. 2*, gave, on reference to a Table, the temperature to be determined. For many years this electrical-resistance pyrometer was the only appliance, believed to be trustworthy, which could be placed in the hands of artificers. Its usefulness was widely recognized, and a Committee of the British Association was appointed to report upon it. The result of the inquiry[1] rather tended to shake confidence in the instrument, as it was shown that it was liable to changes of zero. Mr. H. L. Callendar[2] has, however, done much to prove that, with certain precautions, the method may be rendered very trustworthy. He winds the platinum wire on a plate of mica, excludes reducing gases, as the Committee suggested, by enclosing the coil in a tube of doubly-glazed porcelain, and uses a zero method of measuring the currents with the galvanometer.

Fig. 1.

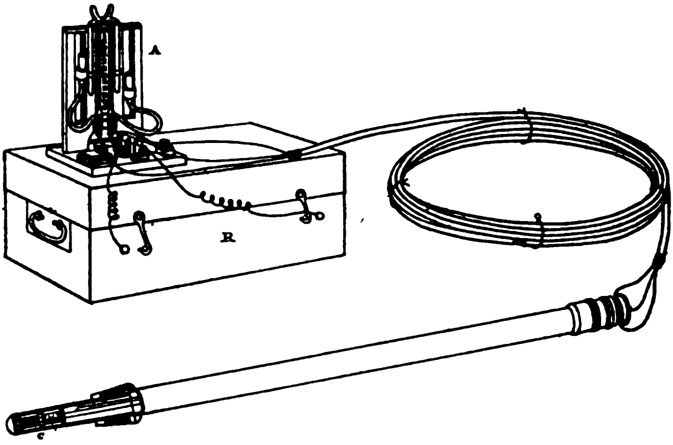
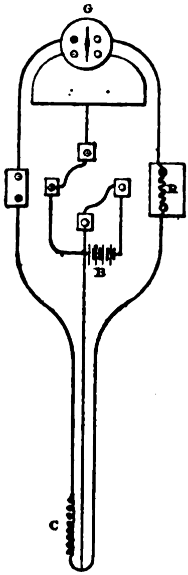


Fig. 2.



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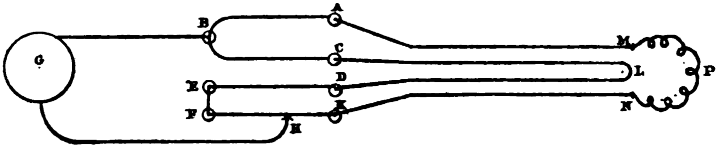
[1] British Association Report, 1874, p. 242.

[2] Phil. Trans. Royal Soc., vol. clxxviii. 1887, p. 161.

Fig. 3 represents, somewhat diagrammatically, the arrangement of the apparatus.[1]

A B, B C are equal resistances, forming the arms of the balance. The battery is connected at A and C, and one terminal of the galvanometer G at B. D E represents a set of resistance coils, which, together with the resistances A B and B C, may be supplied by an ordinary box of coils of the "post-office" pattern. F K represents a straight bridge-wire, with a divided scale attached. The other terminal of the galvanometer is connected to the contact-piece H, which slides along this wire. The leads A M, K N, from the pyrometer coil P, are connected to A and K; and the compensating leads C L, L D, the resistance of which is equal to A M, K N, are connected to C and D. These four leads may be of any convenient length; they are symmetrically arranged, so that corresponding parts are always at the same temperature. When the balance is found by inserting suitable resistances in the arm D E, and sliding the contact-piece H, it is plain that, since the resistances A B, B C, are equal, the resistance of the pyrometer and its leads, together with that of the length H K of the bridge-wire, will be equal to the remaining portion F H of the bridge-wire, together with the coils D E, and the compensation C L D. Thus, the changes of the resistance of the pyrometer-leads A M, K N, are compensated by the equal changes in the leads C L, L D, and the resistance of the pyrometer-coil itself is directly given by the sum of the coils D E, and the reading of the bridge-wire. The resistance of a centimetre of the bridge-wire F K is made to correspond to such an increase of the resistance of the pyrometer coil P, as is produced by a rise of 1° C. The contact key H slides along this wire, and the galvanometer can easily be made sensitive to one-hundredth of a centimetre of this bridge-wire; so that one-tenth of a centimetre, which corresponds to one-tenth of a

Fig. 3.



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[1] Phil. Magazine, vol. xxxii. 1891, p. 104, and vol. xxxiii. 1892, p. 220.

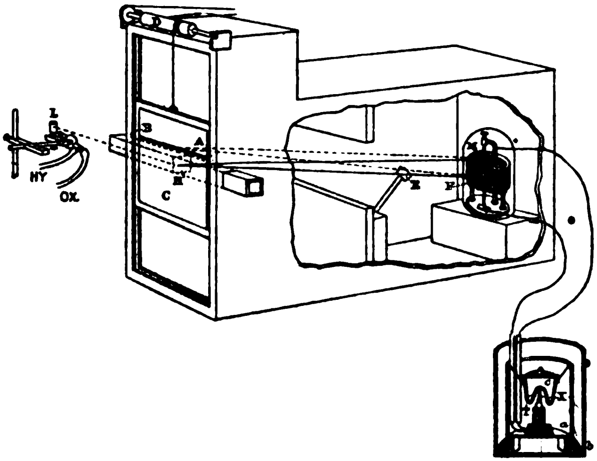
degree, can, of course, be measured with certainty. The Author has worked for several days at the Royal Mint with Mr. Callendar, and is satisfied that, at temperatures exceeding that of bright redness, the comparative readings are accurate to one-tenth of a degree. This would have been considered impossible a few years ago, and the statement will, perhaps, be received with some incredulity. Later on, evidence will be examined which leads to the belief that, in the measurement of a "white-heat," degrees of value similar to those of the ordinary mercurial thermometer are still employed.

Measuring the increased resistance of a heated conductor is not the only way in which electricity has been made serviceable in the measurement of high temperatures. It has long been known that if a junction of two metals be heated, the electrical equilibrium of the system is disturbed, and the measurement of the difference of potential produced affords a means of estimating the temperature of the junction. The use of such thermo-junctions appears to have been suggested by A. C. Becquerel in 1826, and adopted by Pouillet ten years later. Unfortunately, the metals composing the thermo-junctions were badly chosen, and their use was consequently greatly retarded until, within the last few years, Professor H. Le Chatelier, of the École des Mines, Paris, advocated the use of platinum, in conjunction with platinum alloyed with 10 per cent. of rhodium. The Author first adopted this couple in 1889, and has since constantly used it, in conjunction with a photographic recorder, devised for the purposes of an investigation which was entrusted to him by the Institution of Mechanical Engineers. In its latest form, the instrument consists of two wires, one of the metal, and the other of the alloy mentioned above, simply twisted at their ends or soldered with gold, and connected with a dead-beat galvanometer of about 200 ohms resistance. The Deprez and D'Arsonval form of galvanometer, particularly the latest type of this instrument, is admirably adapted for use with this thermo-couple.

The arrangement, which is shown in *Fig. 4*, consists of a galvanometer of the Deprez and D'Arsonval type enclosed in a large camera; a fixed mirror F is placed below the movable mirror M of the galvanometer, so that the light from the lime cylinder L, reflected in the mirror H, passes to both mirrors, F and M, and is reflected in the direction of a fine horizontal slit A B; behind which a sensitized photographic plate C is drawn vertically past the slit, by means of gearing D driven by clockwork. The ray from the fixed mirror is interrupted periodically by the vane E, and a beaded datum-line is given, which enables any irregularity in the advance of the plate to be detected.

The amount of divergence, from its datum-line, of the spot of light reflected by the movable mirror at any given moment, bears a relation (which can readily be found by calibration) to the temperature to which the thermo-junction X is heated; and the variations of temperature are denoted by a curve which is the resultant of the upward movement of the plate and the horizontal movement of the spot of light. A crucible *c* which may be filled with molten metal, is provided with a tubulure T for the insertion of the thermo-junction. The crucible is suspended by wires in a double jacket of tin plate, *a*, *b*.

Fig. 4.



The Author is satisfied that this thermo-junction can afford trustworthy results, accurate to 1°, at temperatures of over 1,000° Centigrade. One important feature of the appliance is the minuteness of the space occupied by the thermo-junction, which may be suitably protected, and inserted into the midst of a very small mass of metal. The pyrometer is calibrated by exposing the thermo-junction to certain known temperatures, such as the solidifying points of salts or metals. There is no difficulty in recognizing the melting or the solidifying points; for, as the mass passes from the solid to the fluid state, the temperature remains constant for a brief period, the duration of which depends on the amount of material operated upon, and its latent heat of fusion; the result being that the spot of light from the galvanometer will be arrested and the position on the scale, at which it stops, marks the temperature to be determined.

The electromotive-force produced by heating the thermo-junction to any given temperature, is measured by the movement of the spot of light on the scale, and, as has been above indicated, the scale is calibrated by heating the thermo-junction in contact with substances of known melting points.

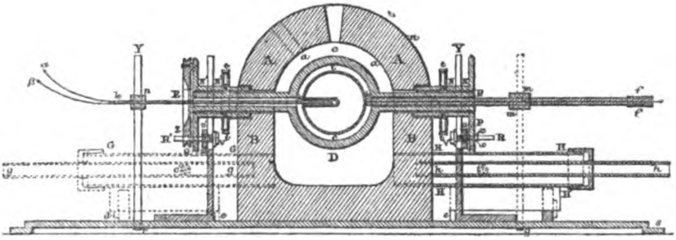
The following list gives a sufficient number of such fixed points, which have been established by concurrent evidence of various kinds :—

100°	Centigrade	. .	Boiling point of water.
326°	„	. .	Melting point of lead.
358°	„	. .	Boiling point of mercury.
415°	„	. .	Melting point of zinc.
448°	„	. .	Boiling point of sulphur.
625°	„	. .	Melting point of aluminium.
665°	„	. .	Boiling point of selenium.
945°	„	. .	Melting point of silver.
1,015°	„	. .	„ „ potassium sulphate.
1,045°	„	. .	„ „ gold.
1,054°	„	. .	„ „ copper.
1,500°	„	. .	„ „ palladium.
1,775°	„	. .	„ „ platinum.

They rest mainly, however, on determinations made with the air-thermometer. This valuable appliance need not be here described. It will be sufficient to state that its principle is the same as that on which the ordinary thermometer depends; the mercury being replaced by a gas, the expansion of which can be measured, and the glass bulb by a globe of porcelain.

The question naturally arises, how far may the indications afforded by the air-thermometer be trusted? Are the degrees indicated by it, at a white heat, comparable with the degrees of the ordinary thermometer? The Author believes that there is no reason to expect exceptional deviations from Boyle's law at the high temperatures of ordinary furnaces; and, further, the evidence as to temperature indicated by the air-thermometer does not rest upon the expansion of a single gas; as the porcelain bulb may be filled with nitrogen, oxygen, or carbonic anhydride. The question as to the degree of confidence which may be reposed in the numerical values of high temperatures is, however, so important, that the Author would refer to the following experiment of Carl Barus, who has devoted years of patient work to pyrometric investigations. *Fig.* 5 shows the arrangement adopted by him for comparing directly the air-thermometer with the thermo-junction.[1] The latter is inserted in a tubulure extending to the centre of the bulb *e*; and the disposition of the various parts of the apparatus is as follows. The walls of a cylindrical furnace B B are covered with a hemispherical dome A A. The furnace is heated by gas, introduced through the burners G G, H H; compressed air entering by the inner tubes *g g* and *h h*. The inlets for the gas are shown at *c c'*. The furnace can be heated to a high temperature with ease; but in order to equalize the heat, Barus employs an internal globular "muffle," E C D F. It consists of two hemispheres of fire-clay, provided with lateral tubes, which pass through the walls of the furnace. The two hemispheres are held together by the iron collars N N, N′ N′. The outer edges of these collars P P′ are flanged, and fit into the grooves of two friction rollers, Q Q′, of which R R′ are the respective axes. There are adjusting screws at V V′, *u u′*, *t t′*. The muffle is rotated by a belt pulley screwed on to the flange P′. The air thermometer is shown in position, *f f k i e*, supported by the clamp *m m*. A similar clamp *n n* on the opposite side of the furnace, supports the thermo-junction *k k*, the wires of which are shown at *α β*. It will be observed that the thermo-junction passes directly into the re-entering tubulure of the porcelain bulb; but the wires must not touch the walls of the tubulure. The capacity of the bulb *e* is about 300 cc. The muffle is turned at the rate of about fifty revolutions per minute; and this speed, which is probably needlessly high, ensures uniformity in the temperature of the furnace.

Fig. 5.



It will be evident that the arrangements briefly described above enable the indications of the air-thermometer and the thermo-junction to be compared, and full details of the experiments will be found in a monograph by Barus. It will be found[1] that, if the results of the experiments be plotted with the electromotive-force of the thermo-junction (in micro-volts) as abscissæ, and the temperatures, indicated by the air-thermometer, as ordinates, the several observations coincide very nearly with a straight line; and singularly valuable information is thus afforded as to the trustworthy character of the respective methods. The general conclusion would appear to be,—that the thermo-junction, the use of which is very simple, may replace the air-thermometer, which, as arranged for accurate work, involves the employment of cumbersome apparatus and much tedious calculation; and is, in fact, about the last piece of apparatus that should be offered to engineers, with a view to the measurement of temperatures in the ordinary course of work.

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[1] Bulletin United States Geological Survey, No. 54, Washington, 1889.

An air-thermometer in a form adapted for industrial use has, however, been devised by Professor Wiborgh, of Stockholm,[2] who measures the pressure exerted by the expansion of a known volume of air, when forced into a porcelain bulb raised to the temperature which it is required to determine. Another form has recently been patented by Mr. H. L. Callendar;[3] who has so modified the differential air-thermometer as to enable the degrees of temperature to be read directly on a graduated tube.

In conducting researches, the thermo-junction possesses, in the Author's opinion, many advantages; but, unfortunately, its use involves appliances which are not sufficiently simple to be entrusted to ordinary workmen; and, as Professor Le Chatelier has pointed out, the use of the thermo-electric pyrometer is only possible in works where the engineer has a taste for scientific investigation, and devotes himself personally to it. In this country such cases are not rare, and the Author would only cite, as an instance, the Clarence Works; where Sir Lowthian Bell has established a system of electrical pyrometry in connection with the hot-blast mains; each of which may, in turn, be placed in pyrometric communication with a central office.

A less complicated but still trustworthy instrument of moderate accuracy was much needed; and Professor Le Chatelier has recently supplied one. The eye of the workman again becomes the pyrometer, but it is supplemented by an instrument which enables him to record the intensity of the radiations emitted by a glowing body; so that the old method of judging temperature by the appearance of the mass is rendered comparatively accurate, and the familiar indications of "redness," "bright redness," and "whiteness," are subjected to direct measurement. Optical pyrometry is not new; but its history, which would include references to the honoured names of Pouillet, Ed. Becquerel, Crova, and Violle, is far too complex to be dealt with in this Paper.

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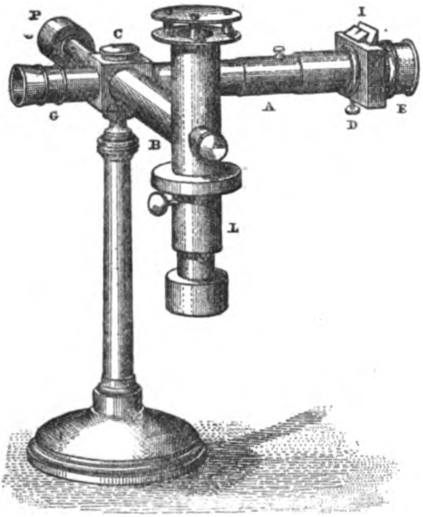
[1] *Loc. cit.*, p. 226.

[2] Journal of the Iron and Steel Institute, 1888, vol. ii. p. 110.

[3] Proceedings of the Royal Society, 1892, vol. l. p. 247.

Mr. Crova[1] actually employed his spectro-pyrometer for industrial work, and measured the temperature of certain furnaces at the Creusot Works.

Fig. 6.



Le Chatelier's[2] new photometric instrument is shown in *Figs. 6*, *6a*, and in its construction he has introduced the photometer of Mr. Cornu. The Author is indebted either to Le Chatelier's recently published Papers, or to descriptions which he has furnished, for the details respecting the instrument which will now be described. The light, from a standard flame, or lamp L, burning amylic acetate, is reflected to the eye of the observer by the mirror M, while the light from the incandescent body also passes to his eye through a red glass in the eye-piece G; this renders the radiations nearly monochromatic. There is an adjustable orifice at O, by which the amount of light admitted from the luminous body can be regulated. In order that intensities, which may often vary from 1 to 1,000,000, may be compared, absorbent glasses are employed; and these glasses are superposed at O′ and E, in greater or less number, as may be necessary. P is a counterpoise, to equalize the weight of the other parts of the appliance. The luminous object, the temperature of which has to be determined, may be focussed by sliding the tube A′; and in order to measure the intensity of its radiations with this instrument, the procedure is as follows:—The position of the mirror M must be regulated by three screws at C, *Fig. 6*, so that the luminous image of the lamp, and that of the object to be measured, are brought into juxtaposition, being divided by the edge of the mirror.

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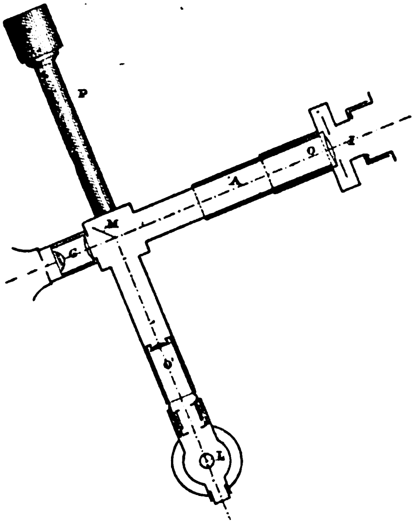
[1] Comptes Rendus, vol. lxxxvii. 1878, pp. 322 and 979; *ibid.* vol. xc. 1880, p. 252; *ibid.* vol. xcii. 1881, pp. 36 and 707; *ibid.* vol. cxiv. 1892, p. 941.

[2] Comptes Rendus, vol. cxiv. 1892, p. 214; l'Industrie Électrique, No. 7, 1892, p. 147, where the formulas given in this Paper will be found.

Fig. 6a.



The photometer depends upon the adjustment, to the same brightness, of two images; one being that of the flame of a standard lamp, and the other that of the object whose temperature is to be determined. The adjustment is made by means of a diaphragm formed of two plates, each with V-shaped notches opposite to one another. The two plates can be moved past one another by turning a milled head, D, and in this way a square aperture of variable size is formed; which, being placed in front of the object-glass O of the telescope, controls the amount of light admitted from the luminous object.

A divided scale I is attached to one half of the diaphragm, and a pointer to the other, and this gives directly a linear measurement n of the aperture.

Let n' be a measurement, when the image of an object of unit brightness (a candle-flame for instance) is matched to that of the standard lamp; and n the measurement, when another object is matched in place of the candle. Since the eye-piece has a red glass within it, only red rays pass to the eye for measurement, and the intensity I, of these red rays emitted by the second object, as compared with those from the candle, will be given by the equation

$$\mathrm{I} = \left(\frac{n'}{n}\right)^2.$$

But, if the two objects are not at equal distances from the instrument, the intensity will be apparently less for the more distant one, in the ratio $\left(\frac{f}{f'}\right)^2$, where f and f' are the focal lengths (given on the tube A) of the two objects; hence—

$$\mathrm{I} = \left(\frac{n'}{n}\right)^{2} \times \left(\frac{f}{f'}\right)^2.$$

As has been already stated, the great differences of intensity which have to be measured, occasionally render it necessary to absorb some of the rays from the object or from the standard lamp, as the case may be. This is done by inserting neutral-tinted glasses in suitable holders, either at E or F. Let N' be the linear measurement of the aperture, when the luminous object, shaded by a neutral tinted glass, is matched with the standard lamp; and let N be a similar measurement when the same object is unshaded.

Then the coefficient of absorption of the glass, K, will be given by the equation

$$\mathrm{K} = \left(\frac{\mathrm{N}'}{\mathrm{N}}\right)^2;$$

and, when p thicknesses of the neutral glass are before the object, whilst the standard lamp is left unshaded,

$$\mathrm{I} = \left(\frac{n'}{n}\right)^2 \left(\frac{f}{f'}\right)^2 \left(\frac{\mathrm{I}}{\mathrm{K}}\right)^p.$$

On the other hand, for measuring very low temperatures, when the standard lamp is shaded by p thicknesses of glass, and there are no glasses before the diaphragm, the formula becomes

$$I = \left(\frac{n}{n}\right)^2 \left(\frac{f}{f'}\right)^2 K^p,$$

the index p being required because each glass cuts off a fraction of the light received by it.

Experiments indicate that the change in intensity of the red rays from a body of temperature T, is approximately given by the equation

$$I = 10^{6 \cdot 7} T^{-\frac{3210}{T}},$$

where T is reckoned from absolute zero, so that $T = (t\,°C + 273)$, t being the actual reading of the thermometer. This formula has been used to calculate the numbers given in the following Table—

Temperature. Centigrade.	Intensity of Red Rays.
600°	0·00008
800°	0·0046
1,000°	0·078
1,200°	0·64
1,400°	3·35
1,600°	12·9
1,800°	39·0
2,000°	93·0

the unit intensity being that of the axial zone of the flame of a standard candle.

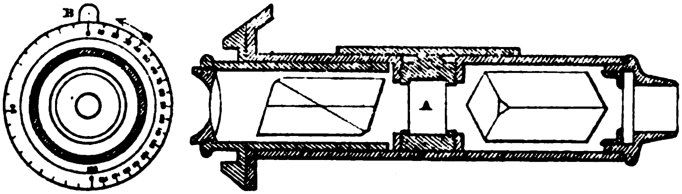
In one instrument, where n' (the reading obtained with a candle flame as a luminous object) was 5·2, and $\frac{1}{K}$ had the value $\frac{1}{25}$, the following figures were obtained by Professor Le Chatelier:—

Temperature.	One Glass before Standard Lamp.	No Neutral Glasses.	One Glass before Diaphragm.	Two Glasses before Diaphragm.
Centigrade.				
700°	39·5			
800°	15·2			
900°	7·4			
1,000°	3·8	19·2		
1,100°	..	10·8		
1,200°	..	6·7		
1,300°	..	4·2	21·2	
1,400°	..	2·7	13·8	
1,500°	..	..	10·1	
1,600°	..	..	7·4	
1,700°	..	..	5·6	
1,800°	..	..	4·3	21·5
1,900°	..	..	..	17·0
2,000°	..	..	..	13·8

But, inasmuch as the emissive power of different bodies for red rays is not the same under like conditions as to temperature, it will be doubtless preferable to calibrate the instrument directly by comparing it with a little mass of platinum, or of oxide of iron, which can be maintained at known temperatures as measured by a thermo-couple.

There is another optical instrument, the pyrometer devised by Messrs. Nouel and Mesuré,[1] and used by the Author for some years in the laboratory of the Royal School of Mines. It consists of a quartz plate A (*Fig. 7*) placed between two Nicol prisms; an arrangement that renders it possible to suppress, at will, the radiations of any particular part of the spectrum, by simply rotating one of the Nicol prisms. If a hot body be observed through the instrument, and the prism be rotated by means of the divided head B, the red colour of the body will be seen to change to yellow, then to green, and finally to blue. The angle of rotation necessary to extinguish the red colour varies with the temperature, and serves as a measure of it; but the difficulty of remembering the precise tint by which the instrument was calibrated, prevents a high degree of accuracy from being attained in its use.

Fig. 7.



The importance of being able to measure high temperatures will now be considered with special reference to the work of the engineer. It is evident that the advantages of measuring and controlling the temperatures at which industrial operations are conducted, are more apparent on the metallurgical side of engineering practice than on any other; but, apart from metallurgy, there are many problems in the solution of which pyrometry is of much service. The unaided eye, even of a trained and skilful workman, dealing with a special set of conditions with which he is familiar, is, probably, a far less trustworthy guide than it is often supposed to be; for, in estimating the temperature of a furnace, or that of a glowing mass of metal, much will depend upon the relative brightness of the illumination of the surrounding space. The Author has had considerable experience in estimating the somewhat high temperatures of the "muffles," or little ovens used in the assay of gold and silver; but, on actually measuring, by means of the optical pyrometer, the temperature of two muffles in different positions in the same laboratory, he was surprised to find that they differed by more than 50°, although both appeared to be of nearly the same temperature.

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[1] Minutes of Proceedings Inst. C.E., vol. lii. p. 419.

Some measurements, made by the optical pyrometer, of temperatures employed in conducting industrial operations will now be given:—

Gold Melting, Royal Mint.

	Centigrade.
Temperature of standard alloy, pouring into moulds	1,180°
,, ,, ,, (on a previous occasion, by thermo-couple)	1,147°
Annealing blanks for coinage, temperature of chamber	890°

Silver Melting, Royal Mint.

Temperature of standard alloy, pouring into mould	980°

Open-Hearth Furnace, Woolwich Arsenal.

Hot gases in interior of melting chamber, about	1,800°
Temperature of steel, 0·3 per cent. carbon:	
Pouring into ladle	1,700°
Pouring into moulds	1,700°
Pouring into moulds at end	1,650°

10-Ton Open-Hearth Furnace, Woolwich Arsenal.

Temperature of steel, 0·3 per cent. carbon, pouring into ladle	1,645°
Temperature of steel, 0·3 per cent. carbon, pouring into large mould	1,580°
Re-heating furnace, Woolwich Arsenal, temperature of interior	930°
Cupola furnace, temperature of No. 2, cast-iron pouring into ladle	1,600°

It is, of course, useless to attempt to deduce the temperature of a heated space, such as the interior of a re-heating furnace, from the radiations of an object which has been newly placed in it, and has therefore not had time to become thoroughly heated. Some experience in the use of the instrument is necessary, but the Author does not find that there is much divergence between his observations and the results obtained by his assistant, Mr. H. C. Jenkins, Assoc. M. Inst. C.E.

Professor Le Chatelier[1] had previously measured the temperature attained in conducting some familiar operations; and, as the results obtained by him are, in the case of certain industries, entirely at variance with the estimations which have hitherto been made, it may be of interest to quote a few of them:—

BESSEMER CONVERTER (6 TONS CAPACITY).

		Centigrade.
Pouring of the slag		1,580°
„ „ steel into ladle		1,640°
„ „ „ into mould		1,580°
Re-heating furnace		1,200°
Ingot under the hammer		1,080°

SIEMENS-MARTIN OPEN-HEARTH FURNACE.

Gas—		
Temperature of gas on leaving generator		720°
„ „ „ entering regenerative chambers		400°
„ „ „ leaving „ „		1,200°
„ „ air „ „ „ „		1,000°
„ „ products of combustion approaching the chimney		300°
Metal (about $\frac{3}{10}$ per cent. carbon)—		
Temperature at end of fusion of pig-iron		1,420°
„ „ "fining" of the steel		1,500°
„ „ pouring of the steel into the ladle	beginning	1,580°
	end	1,490°
„ „ „ „ „ into the mould		1,520°

REGENERATIVE FURNACE FOR CRUCIBLE STEEL.

Temperature in the spaces between the crucibles	1,600°

BLAST FURNACE, SMELTING GREY PIG.

Opening in front of the "tuyere"		1,930°
Tapping the pig	beginning	1,400°
	end	1,570°

SIEMENS FURNACE, USED FOR MELTING GLASS.

Furnace	1,400°
Melted glass	1,310°
Annealing the bottles	585°

Furnace for hard porcelain, end of the "baking"	1,370°
Hoffmann kiln (brick-burning)	1,100°
Temperature of incandescent electric lamps from	1,800° to 2,100°

The accurate measurement of high temperatures is increasing in interest, in view of the rapid development of the study of chemical dynamics.[1] It is now recognized that the industrial chemist, as well as the engineer, has to deal with the influence of mass. Many chemical processes are reciprocating, so that the original product may be obtained from the product of the reaction. The result of such opposed processes is a state of chemical equilibrium, in which the original and the newly-formed substances are present in definite quantities; and remain the same so long as the conditions, more especially those of temperature and pressure, do not undergo further change. In conducting many operations, temperature and pressure are reciprocal factors; thus, in the manufacture of oxygen on an industrial scale, from air, by the intervention of oxide of barium, the latter is heated to a constant temperature of 700° Centigrade, and the air is admitted to the heated mass under a pressure of 1½ atmosphere; while the oxygen, then absorbed, is again evolved, if the containing vessel be rendered partially vacuous. It is evident that, at a certain critical temperature and pressure, the slightest variation of either will destroy the equilibrium in such a system, and induce chemical change. Hence the importance of being able to measure with accuracy a bright red heat. Now, as Professor Le Chatelier has already pointed out, in the production of chlorine by the Deacon process, or in the baking of porcelain, a variation of temperature of only 20° is attended with complete failure of the operation. There is, however, one other case of more direct interest to the engineer, in relation to steel. It involves the consideration of the possibility of the occurrence, at high temperatures, of molecular changes in steel, which profoundly modify its mechanical properties; and although it is difficult to describe briefly the nature of this change, the following statement may be sufficient.

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[1] Comptes rendus, vol. cxiv. 1892, p. 470.

When a mass of steel is cooled from a very bright red heat, say from 1,200° Centigrade to the ordinary temperature of the atmosphere, at least three critical points, each attended by an evolution of heat, may be detected by the pyrometric methods already indicated; and their position may be determined very precisely by the aid of the autographic method already described and illustrated. The development of the theory of the importance of these critical points is mainly due to Osmond,[2] who has fixed the normal temperatures at which they occur during the slow cooling of a mass of steel; and these are approximately as given in the following Table, in which the notation of Chernoff and of Osmond has been retained.

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[1] Roberts-Austen, Presidential Address, Chemical Section of the British Association. Cardiff, 1891.

[2] See Report by the Author to the Alloys Research Committee of the Institution of Mechanical Engineers. Proceedings, No. 5, 1891, p. 543, and 'Nature,' vol. xli. 1889, pp. 11, 32, where references are given to Osmond's Papers.

	Centigrade.
A_1 Is caused by the change of "hardening carbon" into carbide of iron (Fe_3C), and occurs when the temperature of the cooling mass has fallen to about	650°
A_2 Coincides with the appearance of magnetic properties in the iron. It is due to an allotropic transformation in the iron, and occurs between	700° & 740°
A_3 Is also due to an allotropic modification in the iron, and normally occurs at	855°

The Author believes that these changes are of great importance in modifying the structure, and consequently the mechanical properties, of steel; and he is fortunate in sharing this opinion with Dr. Anderson, the Director-General of Ordnance Factories, who is instituting, at Woolwich Arsenal, some interesting experiments bearing on the question. The initial temperature of the mass, and its rate of cooling, are not without influence on the temperatures at which these critical points occur. For instance, in hardening large pieces of steel, such as the "A" tubes of guns, it may happen that, when the mass is plunged into the oil bath, a portion of the metal may be at a temperature below that at which the molecular transformations occur. In large masses of steel, the bath may exert a "hardening" action on the hot interior of the mass of steel, and none at all on the cooler surface. It is, moreover, only necessary for the temperature of different parts of the mass to vary within a narrow range, in order that the bath may exert different influences on adjacent parts of the steel. This is a matter of great importance, and Mr. Barba of the Creusot Works began its study in 1880, but abandoned the attempt for want of sufficiently exact and practical methods of measuring high temperatures. The Author attacked the problem last year, and published the results of the only experiment which has, as yet, been made. For the purpose of conducting it, Dr. Anderson caused an ingot of steel to be prepared, 8 inches high and 4 inches in diameter. It contained carbon 0·799, silicon 0·084, manganese 0·412. A Le Chatelier thermo-junction was placed in a hole drilled to the centre of the mass, and another thermo-junction was fixed in a hole drilled near the surface. The mass was heated to bright redness, the external junction indicating 1,100° Centigrade, each thermo-junction being in turn switched into connection with the recording apparatus, *Fig. 4*; and dotted curves representing the cooling of the exterior and at the interior of the mass were thus obtained. The cooling was effected by plunging the mass into water. The effect of rapid cooling on the surface was, of course, to contract it and to compress the mass; the pressure being very marked in the zone of the ingot in which the external thermo-junction was inserted. The result appeared to be a lowering of the critical point (which should have occurred at about 660° Centigrade) to a little over 400° Centigrade.

It would therefore appear that the great problems of chemical equilibrium are applicable to the relations between the constituents of the complex material, steel; and that the pressure exerted on the molecules of a metallic mass must be measured, as well as its temperature, in investigating the molecular grouping of metals, upon which their mechanical properties depend.

In conclusion, it may be well to indicate briefly some other directions in which the measurement of high temperatures may be useful. The spent gases from boiler-furnaces are often hotter than 400°, and their temperature should, in many cases, be accurately known. In researches on heat-engines, complex problems arise demanding a knowledge of temperatures of about 500°. Foundry practice presents numerous cases, as, for instance, casting guns by the Rodman system; in conducting which it is most important, as Mr. H. B. Howe, of Boston, has pointed out, to be able to measure and control the rate of cooling of the core of the gun, as compared with its outside. By this means, it is possible to avoid setting up prejudicial stresses, and to promote the development of useful ones in castings of all kinds. Mr. George Addy has appealed to the importance of pyrometry, in connection with experiments on armour-piercing projectiles; and it will be evident that the use of projectiles and explosives is a branch of engineering fertile in problems, the solution of which must, in a great measure, be based on pyrometry.

The gradual introduction of new alloys is changing the methods of investigation which must precede and govern the use of materials in construction. It may be thought that work of the kind indicated in this Paper is not sufficiently practical to deserve the attention of the engineer. If fears of this kind should arise, the Author would recall the eloquent words recently addressed by a Member of Council[1] of this Institution to such doubters; who, he says, "can never have been placed in positions of responsibility, where the safety of ships, the lives of their passengers and crews, the efficiency of armaments, and their own financial position were in question; they can never have looked at masses of steel, with the view of deciding whether they were fitted for the purpose for which they had been produced; nor can they ever have felt the helplessness, and the want of reasonably secure guidance, which it is still the lot of the responsible judge to experience." The guidance for which Dr. Anderson appeals can only be afforded by employing to the fullest extent, the methods, as well as the results, of physical and metallurgical research.

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[1] The Director-General of Ordnance Factories.

The Paper is illustrated by Diagrams, from which the *Figs.* in the text have been prepared.

Discussion.

Professor Roberts-Austen.

Professor Roberts-Austen desired to call attention to the use of the singular liquid-alloy of potassium and sodium which had been adapted to the ordinary purposes of the thermometer by Messrs. Baly and Chorley. There were thermometers on the table, constructed with alloy in ordinary capillary tubes. The boiling-point of mercury, 360° Centigrade, was much below that at which glass softened, and the thermometers might be used to 600° with safety. He hoped that this new method, which they now had at command, would be fruitful in results. The thermometers would soon be available for general use, as Messrs. Baly and Chorley intended to offer them to the public. Professor Austen wished to demonstrate the use of the thermo-junction by some experiments that had been arranged. Placing an ordinary thermometer in a receptacle containing water which was losing heat to a cold environment, the mercurial column would fall until the water began to freeze, and would then remain constant until the whole mass of the water was frozen. If the curve could be traced by an autographic recorder, it would be found that the mercury gradually fell till the water froze, was arrested during freezing, and finally resumed its course and continued until the metal became quite cold. It was precisely the same when a metal cooled and solidified. To show the freezing-point of gold, he had a graduated scale, 40 feet long, representing the scale of an ordinary thermometer divided into temperatures higher than were ordinarily obtainable, 600°, 800°, 1,000°, and so on. The little thermo-junction, a wire of platinum twisted with one of platinum alloyed with 10 per cent. of rhodium, was placed in a crucible under an oxyhydrogen flame, and was connected with a galvanometer; the ray of light from its mirror was reflected, giving a luminous image divided by a fine line, which was thrown on the screen. When the thermo-junction was heated, the spot of light traversed the scale. As the gold melted, there was a sharp arrest at 1,045° Centigrade, and then the spot of light resumed its course along the scale. There was another and still more delicate experiment, showing the freezing-point of palladium at 1,500° Centigrade. The freezing-point of gold had been many times accurately determined, and might be taken at 1,045° Centigrade. He had a mass of palladium placed on a new

Professor Roberts-Austen.

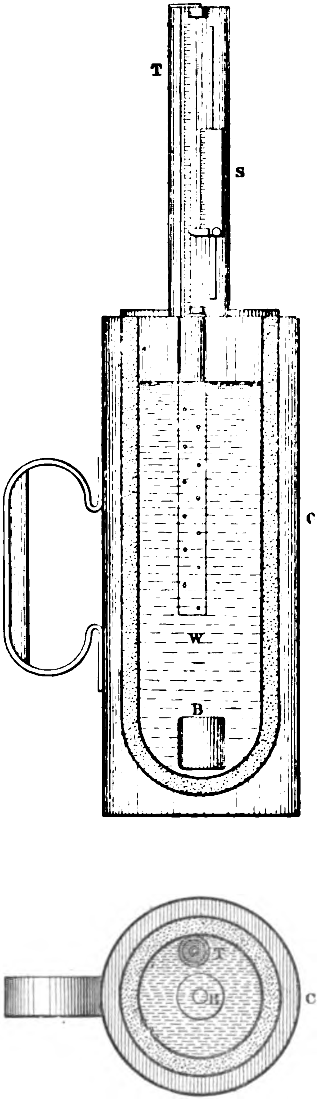
junction, and, by its aid, the melting-point (and the freezing-point) of palladium was clearly shown to be 1,500° Centigrade. He would next show the recalescent point of iron. Another junction was connected with a small ingot of steel, $\frac{1}{2}$ inch across, containing 0·6 per cent. of carbon. It was heated by a blowpipe until the temperature reached about 1,000° Centigrade, and then the mass was allowed to cool. A definite arrest was seen (not, however, at the freezing-point, because the mass had never become molten) at about 680° Centigrade. The precise point at which the change occurred varied with the carburization of the metal.

Mr. Cowper.

Mr. E. A. Cowper said that the thanks of the Institution were certainly due to the Author for arranging the experiments just witnessed. He had tried the instrument at the Mint for testing the temperature of incandescent coke. Mr. Cowper had used his own judgment as to the temperature, and had found it confirmed by the use of the instrument. Instruments of that kind were of immense importance in metallurgy, much more so than might appear to an ordinary observer. The way in which they had been applied in the making of Bessemer steel, especially the spectroscope, had led to many experiments and to great progress in the art of making the best and toughest steel. Some years ago he had required to try the temperature of air heated to a very high degree in certain stoves that he had constructed; and he reverted to the old experiment of Mr. Thomas Wilson, made in 1852,—taking a piece of platinum and heating it in the furnace, or the place where the temperature was required to be gauged, then dropping it into a basin of cold water, afterwards weighing the platinum, measuring the water, and calculating, from the rise in the temperature of the latter, what the heat of the original piece of platinum had been. Of course, they did not care to use platinum commonly —it was much too expensive—and he therefore used a cheaper and rougher instrument, on the same principle. Whether Mr. Wilson was the first to use the method of mixtures to ascertain very high temperatures or not, he did not know; but he thought that was the fact. What Mr. Cowper had done, was to devise an instrument, which he had got his friend, the late Sir W. Siemens, to make, viz., a thin, copper vessel, with a small space for air, and another space for hair felt. A thermometer with a sliding-scale was fixed in the vessel, and a pint of water was poured in. The zero of the scale was placed exactly at the temperature of the water. A piece of copper, having a capacity

Mr. Cowper. for heat as 1 to 50, was placed in the hot blast, and then dropped into the water, which was stirred round, and the highest readings were taken. After a time, it began to cool, and one could at once read on the scale the temperature which the water had acquired by the addition of the hot ball; by adding the original temperature of the water to this, they obtained the temperature of the copper ball when it came out of the hot blast. So accurate was the method that, in a dozen or twenty trials, there would not be a variation of more than three or four, or at most five, degrees. There was no difficulty in getting the exact temperature. Many hundreds of these instruments were now at work at different furnaces. The temperature they commonly gauged was about 1,500° Fahrenheit. *Fig. 8* showed the instrument; T was the thermometer, S the sliding-scale, C the thin copper vessel, B the copper ball, and W the water. The old-fashioned plan of taking the temperature of a blast, was to take a piece of lead, a little thicker than a pencil, and expose it to the blast; and if the lead were "cut" or skinned, and a certain quantity of fluid actually taken from the surface, that was supposed to be the temperature of the melting lead — 620° Fahrenheit, or thereabouts. Then, to get a higher temperature, sticks of zinc were used, then antimony; but they were of no use with a temperature of 1,500° Fahrenheit. They then used the instrument he had mentioned, and by that means they could deal with 1,500° very easily. The arrangement that Sir Lowthian Bell

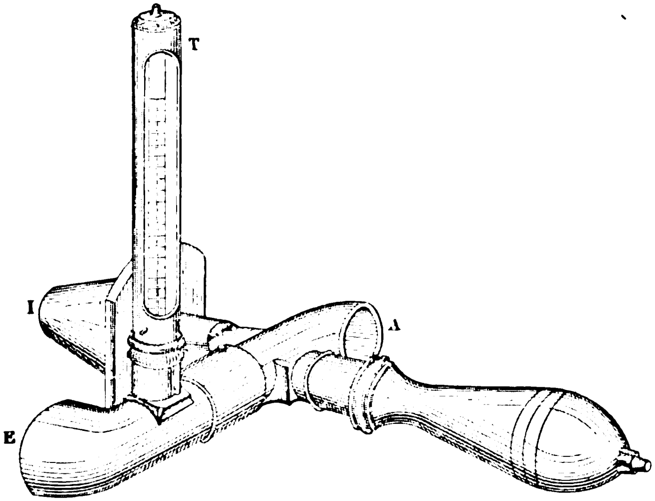
Fig. 8.



Mr. Cowper.

had made, viz., a system of electrical pyrometry in connection with the hot-blast mains of the Cowper stoves, was certainly a very neat and pretty arrangement; because in the office they could simply read on the dial, what was being done at the different furnaces. With a range of twelve furnaces at work, they required to know the temperature very often. Another instrument on a totally different principle, had been designed by Mr. Hobson. A tube was placed into a hole in the tuyere, or "Goose Neck," and there was an opening for the entrance of cold air. A thermometer was thrust into a hole in the instrument, and the current of blast blew through, and induced a current of cold air. The mixture of cold air and hot blast was of such a lower temperature, that the thermometer could stand it, and readings could be taken. It was very correct when they knew the temperature of the air round about the furnace, but sometimes the tuyere house was very hot, and they had to make allowances for that. It was a rough-and-ready instrument, but very handy. *Fig. 9* illustrated the instrument; T was the thermometer, I the inlet for blast, A the entrance for cold air, and E the exit. The blast from the stoves was red-hot for a length of 9 feet of the tuyeres; it was red-hot in daylight, so they might judge of the temperature. He was in hopes, though he had not any great expectation of it, that the Author would show how he took the temperature

Fig. 9.



Mr. Cowper. of air when at a "red-heat" temperature. He supposed a piece of metal, or some other substance, must be put into the blast and allowed to get hot, and then they could take the luminous appearance of the metal or substance so heated. The instrument that had been described in the Paper was a photometer which registered the amount of light given off by the body. Perhaps the Author would not think him very heterodox for saying that he was in doubt as to whether the instrument could deal correctly with a piece of iron a little more than black-hot. They knew how black-hot iron would burn the skin, but there was no light given out from it, and the instrument would not register it. He did not know how far the instrument would measure low temperatures, approaching "black-heat." If light and heat preserved a constant ratio, the light would tell the heat; but, as every instrument of that character had to be calibrated by known temperatures, certain temperatures should be well-ascertained. When calibrated, it would tell exactly what the temperature was, and was therefore a practical instrument for all future use.

Professor Foster. Professor CAREY FOSTER drew attention to the fact that the Author had been melting palladium and carrying on various operations at 1,500° Centigrade. He did not know whether members had noticed that they were Centigrade degrees. What he had been doing at 1,500° Centigrade, meant the same operations at 2,700° Fahrenheit.

Mr. Callendar. Mr. H. L. CALLENDAR thought that the inference of Barus, that the electromotive force of the thermo-couples was proportional to the temperature measured on the absolute scale, was hardly justifiable. If they might judge from the Author's researches with the pyrometer, the temperature-curve was not a straight line —*i.e.*, the electromotive force of the thermo-couple did not appear to be strictly proportional to the absolute temperature. He believed, although he would not speak positively, that the conclusion, that the electromotive force was approximately proportional to the temperature, was arrived at because the air-thermometers could not be made to indicate with sufficient accuracy. It was very difficult to work at those high temperatures with an air-thermometer, and, unless one had actually made experiments, it was hard to realize how difficult it was. It was quite easy to make mistakes of 20° or even 50° at 1,000° Centigrade. So far as he could remember, the conclusion of Barus was, that the electromotive force at high temperatures was only roughly proportional to the absolute temperature. He had had the pleasure of working with the Author at the Mint, and was exceedingly interested in these experiments. The thermo-junction was a wonderfully handy instrument. It was so small that it could be put anywhere in quite a small mass of metal. The experiment at the melting-point of palladium could not be performed with any other instrument that he was acquainted with. As remarked by the Author, the electromotive force of the thermo-junction was very small, and consequently required a very delicate apparatus to measure it. In this respect the method of pyrometry introduced by Sir William Siemens had some advantages. It depended on the increase of electrical resistance, which was large, and was a most simple electrical measurement. Consequently, pyrometers could be made on that principle to read more delicately than thermo-couples. If a sufficiently powerful battery were used they could be made extremely sensitive. In this respect the difference somewhat resembled that between the microphone and magneto-telephone. The magneto-telephone produced its own current, whereas the current working the microphone depended on the strength of the battery; consequently the latter could be made very much more sensitive. In that way, it was possible to make it read to one-tenth of a degree at a temperature of 2,000° Fahrenheit. The Author had referred to some of Mr. Callendar's instruments. He had some exhibited in the Institution, and would be glad to show the members that they were actually sensitive to the extent mentioned by him. With regard to the optical pyrometer, there was this difficulty—that the light radiated depended very much on the source from which it emanated; they could not measure temperatures in this way unless they always used the same standard surface; they could not measure the temperature of hot gas, unless some subtance were put in the gas which would radiate in a known way. Then, again, there was considerable doubt as to the law which this radiation followed. He had seen a great many formulas given for it. Professor Le Chatelier had given a new formula, but, not having had the advantage of reading the original Paper, he was not prepared to discuss it. No doubt it was an exceedingly handy and convenient instrument, if they did not want to measure with any high degree of accuracy. At any rate, an instrument of that kind must be very much more accurate than the eye of a workman, to which most people had to trust in taking the temperatures of furnaces. Mr. Callendar.

Dr. Anderson. Dr. W. ANDERSON said that the subject before them, or at least the latter part of it developed in the Paper, was so intricate and

Dr. Anderson. important that he hardly trusted himself to speak about it, for fearing of saying what he did not intend to say. With regard to pyrometers, those of Siemens, not exactly in the form exhibited but practically the same, had long been in use in the Ordnance Factories and by the Inspection Department in testing steel used in the construction of ordnance. The defect of the instrument was that, on account of its bulk, it could only measure the temperature of the furnace, and not of the article in the furnace; so that errors often arose. The indications of the pyrometer were accurate, but the samples of steel in the furnace were not always at the temperature of the furnace itself. It was on account of the smallness of the thermo-couple that the instrument devised by Le Chatelier was so valuable, for, as was shown on the diagram, it would actually measure the temperature of the article itself. With respect to the Wilson pyrometer, described by Mr. Cowper, it no doubt was good for rough-and-ready work at moderate temperatures; but it had this fatal objection, when considered as an instrument of precision, that the specific heats of the substances used as heaters were not constant throughout the extreme ranges of temperature to which they were heated. Members had seen, by the spot of light thrown upon the scale, that, at a particular temperature, the specific heat of steel must be very different from what it was at other temperatures, because the rate of cooling was completely altered; hence, for accurate measurement, the system of mixtures did not answer; and, in addition, a certain amount of heat was lost in transferring the heater from the furnace to the water. It had, further, this disadvantage, that the temperature of the object could not be measured; and of course, the Paper had to do with high temperatures only, and not with the comparatively moderate temperatures to which Mr. Cowper had alluded. The importance of the question with reference to the treatment of steel was almost greater than he could express. It was not sufficiently realised that all substances, india-rubber included, whether solid or liquid, were incapable of sensible cubical compression, or extension, that is to say, their volume could not be altered, either by extension or compression, in any sensible degree. Consequently, when masses of steel or other alloys were cooled, or heated by the usual means, differences of temperature in the mass must arise, and as there could be no change of volume due to pressure if they were cooled or heated from all sides simultaneously, internal stresses must be set up to a greater or less degree. To what degree of intensity those stresses attained it

Dr. Anderson.

was almost impossible to say, but they knew from long experience, that they did occasionally reach a degree sufficient to cause rupture, which might not show itself at once, but would surely appear sooner or later. It was on that account that he attached the greatest importance to the power of measuring the changes of temperature accurately, because, as appeared from the experiments, there was a critical temperature at a bright-red heat in steel which only covered a range of about 200° Centigrade, in which, as the Author had stated, the most momentous molecular changes took place—changes comparable to those which arose in the liquefaction of ice or the evaporation of water, and which implied a chemical as well as a molecular change in the substance. It was evident that if steel, or any other alloy, was worked at or about that temperature, it was quite possible to obtain—from a change of heat which might not be apparent to the eye of the workman—results which would be totally discordant. In the one case, the operation might be perfectly successful, and in the other it might be disastrous, without any apparent reason for the difference between the two results. In addition, severe stresses were set up by heating or cooling, because those operations, as ordinarily performed, necessitated a difference of temperature of considerable range within the mass itself, compelling, in the case of large masses, both operations to be performed with the utmost caution; those stresses at high temperatures exercised further a considerable influence on molecular as well as on chemical changes; and he had for some time been making inquiries as to the practicability of heating large masses by means of electric currents, because such heating would be of uniform intensity and simultaneous throughout the mass, and would therefore not give rise to internal stresses. He was in great hopes that electricians would be able to contrive means of performing both heating and cooling in this way, and a contingent advantage would be, that the operation would probably be performed in as many minutes as it required hours at present. It was on account of the difficulty and danger of dealing with large masses, that the use of wire in the construction of ordnance was of such great advantage. It was true that in bending wire round a comparatively small diameter, the tension and compression of the outer and inner sides of the wire were considerable; but the amount could be easily arrived at arithmetically on the assumption that no lateral deformation took place. It could thus be shown that bending a $\frac{1}{16}$-inch wire round a 12-inch circle would produce a stress of about 50 tons on the square inch, and it had been

Dr. Anderson. asserted that the wire, when stressed beyond its elastic limit, must be injured to start with, and was therefore unfit to resist further stress. But the mathematical method was incorrect in this respect, that it took no account of the circumstance that the wire was free to alter its shape laterally; it was not a state of cubical compression or extension, it was free to contract on the convex side and to expand on the concave. So that, really, the operation of bending was more like wire-drawing than like the imposition of a stress which was at all calculated to produce rupture; and practical experience showed that wire might be bent round very sharp curves indeed without doing it any great harm. The mass of wire which formed a portion of a gun, for example, was in every part in a condition of advantageous stress, such as it may have pleased the maker to impart; it was known beforehand, and could be arranged as was desired. The danger of using ingot-steel arose from the circumstance that its nature was analogous to that of glass, so that if a crack commenced it was impossible to say where it might end, and how far the cause which apparently produced the crack might make it extend, or whether, if internal and concealed, it would not at last reveal itself in a disastrous manner. In the case of iron which was produced by faggoting and welding bars, a structure analogous to that of wound-wire was arrived at. The wires represented the fibres of the iron, and were separated from each other, so that the cracks did not extend like they did in a homogeneous mass. The benefit of using wire in construction was, that it formed a mass which from its nature could not be stressed cubically, and brought into a dangerous state of internal strain, and further, though one portion of it might be broken through, there could be no crack to extend indefinitely, and they had therefore almost absolute security. The importance of the application of the accurate methods of measurement which the Author had described, and which in future would enable them to tell very much more precisely what they were to expect from the steel they were dealing with, lay in this,—that, from curves automatically traced, they could tell by comparing those traced from shavings or drillings taken from the various parts of a large forging, such as the crank-shaft of a marine engine, or a gun-hoop, whether every portion of the forging gave a precisely similar curve, with kinks showing the molecular changes to have occurred at the same temperature, and to have been of the same intensity. If this were so, it might be fairly said that the whole of that shaft was in the same condition; but if differences appeared they would serve as warnings, and set the maker, by chemical or mechanical tests, to ascertain more precisely the condition of his work. He even believed that, with a little experience, mechanics would be able to say with sufficient accuracy from an examination of the cooling-curves, what the nature of the steel they were dealing with really was—whether it was a kind suitable for their purpose. If they had had before them the number of curves which the Author had obtained from various qualities of steel, and also those which, with a less perfect instrument, Professor Osmond had obtained in France, it would be seen that, with a little experience, they could with certainty detect variations in the nature of steel—whether mild steel or hard steel; and by that means, with an instrument which could be used in a room, the operation of testing not taking more than about twenty minutes, they could obtain an indication of the nature of the material dealt with. His good friend and colleague, Commander Younghusband, who was at the head of the Royal Gun Factories, and on whom primarily fell the heavy responsibility of deciding whether steel was fit to be put into a gun or not, had taken up the matter, and was now, with the Author's assistance, constructing an instrument of the kind exhibited in the room, to be applied in the manner indicated; and he felt sure that very valuable information would be afforded as to this particular application of a beautiful process and apparatus. **Dr. Anderson.**

Professor ROBERTS-AUSTEN, in reply to Mr. Callendar, pointed to Barus' curve (obtained with a platinum, platinum-iridium couple), which he drew on the board. At the lower temperatures, below 300° C., it appeared, from the results obtained by the Author with a platinum, platinum-rhodium couple, that the electromotive-force of the couple was not strictly proportional to the temperature, as the line was curved; but at higher temperatures the line was nearly straight. The experiments of Barus[1] were only quoted by Professor Roberts-Austen to show that the indications afforded by the thermo-couple really represented degrees ordinarily employed in thermometry. He could not approach Mr. Callendar in respect of minute accuracy, but he urged that metallurgists should use the thermo-junction on account of its convenience. Undoubtedly, the resistance pyrometer, as arranged by Mr. Callendar, was more accurate **Professor Roberts-Austen.**

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[1] In the Phil. Mag., July, 1892, Mr. Barus has given details of his method of comparing a thermo-junction with the air-thermometer, which was briefly described and illustrated (*Fig. 5*) in the Paper.—W. C. R.-A.

Professor Roberts-Austen. than anything he had exhibited. He had no reply to make to the remarks of Dr. Anderson, except to express his earnest hope that the methods of observation now laid before the Institution might prove to be of service in our great national factories, and especially in Woolwich Arsenal. The only other observation he desired then to make, was to assure the members of his gratitude for the favourable reception that had been accorded to his Paper.

Correspondence.

Professor Le Chatelier. Professor H. Le Chatelier expressed his gratification at the complete way in which his work had been placed before English engineers and scientific men. He thought it well to insist upon the fact that the development of the method of optical pyrometry would in no small measure depend upon the obtaining of a good standard of light. The Carcel lamp, the "standard candle," and lamps burning either pentane or amylic acetate, were inconvenient in practical work; and it was only in the hands of skilful experimenters that these standards give concordant results. He had recently used the optical pyrometer for estimating the temperature of the electric arc, and had obtained 4,100° Centigrade and 3,000° Centigrade as the temperatures of the carbons respectively, and 7,600° Centigrade for the heat of the sun. The results were not obtained directly by experiment, but by interpolation, and their accuracy was therefore somewhat uncertain. Thus, an error of 50° in the temperature of the molten platinum (1,775° Centigrade), employed in the graduation of the pyrometer, which served as the starting-point of these determinations, would modify by 1,000° the temperature attributed to the sun.

Dr. Obach. Dr. E. Obach observed that the Author had stated that the late Sir William Siemens was the first to utilize the change of electrical resistance in wires for the measurement of high temperatures; and he had also mentioned that Sir William had devised the special form of voltameter shown at A, *Fig. 1*, for use with his pyrometer. Although there was no doubt that a zero method was the most convenient and accurate for measuring resistance, he believed that, at the time of introducing his pyrometer, some twenty or twenty-five years ago, Sir William Siemens

Dr. Obach. did not venture to propose the use of galvanometers and resistance-bridges to practical men for the measurement of high temperatures. Thanks to the untiring efforts of the late Sir William Siemens, Professor Roberts-Austen, Dr. Anderson, and others, matters were at the present time somewhat different, and the importance of truly scientific methods of research, even for technical purposes, was being more and more recognized. Messrs. Siemens Brothers and Co. had ventured some time ago to replace the voltameter hitherto used, by a sensitive differential-galvanometer and a set of resistance-coils. With the electrical pyrometer in its present form, high temperatures up to about 1,200° Centigrade could be easily measured accurately, to within 1° or 2°, which he believed to be sufficient for most practical purposes. The Author had referred to the changes of zero of the electrical-resistance pyrometer as a rather serious disadvantage; but, in regard to that, great progress had been made since the appointment of the British Association Committee in 1874, by a careful selection of the platinum wire, and special attention to the refractory materials with which the wire came in contact. Some years ago, he had an opportunity of re-testing several electrical pyrometers, which had been in constant use at some chemical works for five years, and they were found to be still correct. When the pyrometer was frequently exposed to very high temperatures, the resistance of the platinum spiral might, in course of time, change about four or five per cent.; but, as it was due to a slight stretching of the wire, the temperature coefficient being not affected thereby, it was only necessary to measure the resistance of the wire occasionally at a known temperature, such as that of boiling-water or the atmospheric temperature, and compare it with the corresponding resistance given in the Table accompanying the instrument; then, by multiplying the readings by the ratio of these two resistances, a correction could easily be applied which would give the true temperatures. Referring to the improvements in the electrical-resistance pyrometer recently introduced by Mr. Callendar, he congratulated that gentleman upon his success. He observed from the illustration, *Fig. 3*, that Mr. Callendar employed four leading wires, whereas Messrs. Siemens required only three, in order to completely eliminate the resistance; but whether Mr. Callendar's pyrometer would stand the somewhat rough handling to which instruments of this kind were invariably subjected in practical use, appeared to him to be rather doubtful; this was, perhaps, also the case with the thermo-electric pyrometer devised

Dr. Obach. by Mr. Le Chatelier, which had given such excellent results in the hands of the Author.

Mr. Rowan. Mr. Frederick John Rowan expressed his opinion that there could be no question about the increased importance in the arts, possessed by methods of accurately measuring high temperatures. Engineers, as well as chemists and metallurgists, had frequently need for accurate measurement of the heat employed in many processes, in addition to those mentioned by the Author, who had conferred a benefit on all such workers by giving the results of his experience with the instruments to which he had alluded. Electrical methods promised to be the most generally adopted, although their application in some cases would be attended with difficulty. He had made, about two years ago, an investigation of the temperatures existing in the interior of shale-distilling retorts,[1] and had found that the Murrie tension-pyrometer was the most convenient for some parts of the work. He had considered the question of using a method of measuring the temperatures by means of electrical resistance; but the time at his disposal was not sufficient to admit of his devising means to overcome the difficulties in applying the latter method to that special case. Optical instruments could not afford more than approximate indications, although, in certain cases, these might be of considerable value. When directing the manufacture of Bessemer steel in his father's works, many years ago, he had introduced an optical pyrometer, consisting of a combination of different-coloured glasses, through which the changes of temperature in the flame issuing from the Bessemer converter were recognized with an accuracy not attainable by the unaided eye.[2] Mr. Carl Wittenström, of Stockholm, had constructed an optical pyrometer on somewhat similar lines, employing, however, a number of superposed plates of glass having the same (neutral) tint, and estimating the temperature by the number required to reduce the amount of light that reached the eye, to a standard measure. The pause, or apparent pause, in the cooling of steel at about 680° Centigrade, suggested an inquiry, whether that effect had been observed in steel when allowed to cool uninfluenced by a fire-clay crucible or other envelope? That effect seemed to be different from those observed in Osmond's experiments, when steel was plunged into a bath of oil or cooled in water. In the former experiment, the temperature effect could be accounted for by the difference in the rate of cooling which obtained in the case of fire-brick, as compared with that in the case of steel. Steel, parting with its heat by radiation more rapidly than fire-brick, would obviously outrun that material in cooling, and, in process of time, must reach a point where its rate of cooling would be arrested by radiation from the more slowly cooling envelope. He had not had the opportunity of studying Osmond's Papers, and therefore could not say whether this probable source of error had been anticipated and examined into; but if not, it evidently required investigation. He would be glad if the Author would refer to the matter in his reply. **Mr. Rowan.**

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[1] Journal Soc. Chem. Industry, vol. x. No. 5, May 1891.

[2] This instrument was described in *Engineering*, vol. v. p. 49; also in a Paper read before the Chemical Section of the Philosophical Society of Glasgow, on the 26th March, 1869.

Professor Roberts-Austen. Professor ROBERTS-AUSTEN, in reply to the correspondence, stated that, in regard to Dr. Obach's remarks, he was aware that, in the later instruments supplied by Messrs. Siemens, a galvanometer had replaced the voltmeter, furnished, for industrial use, with the earlier forms of their apparatus. He considered that the thermocouple, suitably protected by a tube of glazed porcelain, was as free from objections on the score of fragility as any instrument could be which was capable of affording useful results in the hands of workmen. Mr. Rowan had asked what effect a heated envelope, in which steel was enclosed, had on the point of recalescence. Varying the rate of cooling of a mass of steel shifted the position of the critical point. Osmond had already shown that a sample of highly-carburized steel gave, when rapidly cooled in air, the recalescent point at 642° Centigrade, while this point in the same steel, when slowly cooled in a porcelain tube, occurred at 671° Centigrade.[1] In most of Osmond's experiments, and in his own, such an influence of the envelope as Mr. Rowan had contemplated had been eliminated, as it was heated and cooled from the outside. No doubt the heat of the enclosing envelope did affect the amplitude of the curve indicating the evolution of heat. The experiment with the steel ingot referred to in the Paper, showed that pressure had a marked influence in lowering the point at which change in the relations of the carbon and iron took place. It would be interesting to determine whether, under the influence of pressure, there was also a change of the temperature at which the combinations of iron with foreign elements crystallized out of a cooling mass of

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[1] Études Métallurgiques, Annales des Mines, July and August 1888.

Professor Roberts-Austen.

steel. Some experiments made by him in 1891 showed that, when a certain mass of steel was very slowly cooled from the molten state, there were, in addition to Osmond's critical points, distinct evolutions of heat, which doubtless corresponded to the crystallization of definite groups of compounds—the presence of which in the solidified mass might be revealed by the microscope. For the present, such questions had been set aside by him, his object being to study the behaviour of the molecule, and not the actions which influenced the coarser mechanical structure of the iron, or the impurities that it contained

LIST OF APPARATUS

EXHIBITED AT THE MONTHLY RECEPTION, 24 MAY, 1892.

Exhibitor.	Objects.
Baird & Tatlock	"Wiborgh" pyrometer.
Professor J. Hudson Beare, B.Sc., Assoc. M. Inst. C.E.	Calorimeter.
	Stress-strain gear.
	Thermometer for high temperatures.
John H. Blakesley, M.A., Assoc. M. Inst. C.E.	"Blakesley" improved surveying-aneroid.
Hugh L. Callendar, M.A.	Pyrometers.
Cambridge Scientific Instrument Company	Reading-microscopes.
	Cup micrometer.
J. Casartelli	"Hobson" pyrometer for use in hot-blast furnaces.
	Six-inch dial-pyrometer for use in flues.
E. A. Cowper, M. Inst. C.E.	Glass bent in a blast of 1,500° Fahrenheit in the "Cowper" stove.
	Copper-ball pyrometer for taking high temperatures of blast in the "Cowper" stove.
	"Hobson" hot-blast pyrometer.
	"Hobson" thermometer for taking the temperature of a mixed current of hot-blast and cold air.
Elliott Brothers	Standard 9-inch calliper-gauge.
	One-inch german-silver micrometer-gauge.
	"Sabine" hand-photometer.
	Improved metallic thermometer.
	"Trotter" template (sine curves).
	"Wollaston" boiling-point thermometer.
John J. Griffin & Sons	Specific-gravity balance.
	"Jolly" specific-gravity balance.
	"Hoskin" hydro-carbon blow-pipe, with muffle and crucible-furnaces.
	Automatic laboratory burners.
	"Bunsen" burners, with arrangement for dispensing with central gas-jet.
	"Crookes" radiant matter tubes.
	Hydrometers (7), with thermometer and trial-jar, for determining the specific gravity of liquids from 700° to 2,000° Fahrenheit.
	Chicago turbines working up to $\frac{1}{13}$ HP.
	Pyro-cones (set of).
James J. Hicks	"Callendar" air-pyrometers (2).
King's College, Strand	"Wedgewood" pyrometer.
Nalder Brothers & Co.	Galvanometer (square case).
	"Kemp" key.
	Transparent lampstand.
	Megohm.
	Set of slides.

Exhibitor.	Objects.
NEGRETTI & ZAMBRA	"Gauntlett" pyrometers (2).
	Pneumatic thermometer.
	Steam-pressure bent thermometer.
	Superheated steam-pressure thermometer.
RICHARD FRÈRES	Direct-reading pyrometer.
	Self-recording pyrometer.
Professor W. C. ROBERTS-AUSTEN, C.B., F.R.S.	"Bystrom" calorimeter.
	"Siemens" calorimeter.
	Improved calorimeter, devised and used by Favre and Silbermann in their investigations on the calorific power of fuels and certain elementary substances.
	Complete installation of the electrical-resistance pyrometer devised by the late Sir William Siemens.
	Complete installations of the thermo-electric pyrometer, and the optical pyrometer described in the Paper, "On the Measurement of High Temperatures."
SCHÄFFER & BUDENBERG	Pyrometers (3).
SCIENCE AND ART DEPARTMENT	"Bystrom" pyrometer.
	"Ferguson" pyrometer.
	"Gallonde" pyrometer.
SIEMENS BROTHERS & Co.	Water pyrometer.
	Electrical pyrometers (2), with differential galvanometer, set of resistance coils, "Hellesen" cells, and leading-wire.
W. H. STANGER, M. Inst. C.E.	Mercurial pyrometer.
WILLIAM SUGG & COMPANY	"Dibdin" photometer.
	"Sugg" photometer (in operation).
Professor W. C. UNWIN, F.R.S., M. Inst. C.E.	Apparatus for the compression of stone, measuring to $\frac{1}{100,000}$ inch.
	Torsion micrometer.
	"Unwin" micrometers (2).
	"Murrie" thermometer for furnace-flues.
ALEX. WRIGHT & Co.	"Wright" photometer.

ANNUAL GENERAL MEETING.

31 May, 1892.

HARRISON HAYTER, Vice-President,
in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 26th of May, 1891, which the Chairman was authorized to sign.

It was moved, seconded, and resolved,—That Messrs. G. R. Bodmer, E. H. G. Brewster, Charles Elwin, A. C. Hurtzig, G. M. Lawford, C. S. T. Molecey, W. F. Pettigrew, Edwin J. White, C. H. Wingfield, and L. S. Zachariasen, be requested to act as Scrutineers for the election of a President, of four Vice-Presidents, and of fifteen Other Members of Council for the ensuing year and that, in order to facilitate their labours, the Balloting-papers be removed for examination at intervals during the time the election remained open.

The Ballot having been declared open at five minutes past eight, the Secretary read the Report of the Council upon the Proceedings of the Institution during the Session 1891–92 (p. 191), the Statement of Accounts being taken as read. After discussion it was

Resolved,—That the Report of the Council be received and approved, and that it be printed in the "Minutes of Proceedings."

Resolved,—That the thanks of the Institution be tendered to the Vice-Presidents and other Members of Council for the assistance they had rendered in promoting its objects.

Mr. Hayter, the senior Vice-President, replied on behalf of himself and his colleagues.

Resolved unanimously,—That the members present at this meeting desire, on behalf of themselves and others, to place on record their high appreciation of the services to the Institution by Mr. Berkley, President, during his year of office.

The Secretary was directed to convey this resolution to Mr. Berkley, with an expression of regret that his absence was due to indisposition.

The Ballot was then declared to be closed, having been open more than one hour.

Resolved,—That Messrs. William Matthews and F. S. Courtney be thanked for the time and trouble they had bestowed in auditing the Accounts for the past financial year; and that Messrs. F. S. Courtney and Samuel Hanna be requested to act as Auditors for the ensuing twelve months.

Mr. Matthews returned thanks.

Resolved,—That the thanks of the meeting be given to Dr. Pole, Honorary Secretary, to Mr. Forrest, the Secretary, and to the members of the staff, for the admirable manner in which they had conducted the business of the Institution during the past year.

Dr. Pole and Mr. Forrest expressed their acknowledgments.

The Scrutineers then announced that the following gentlemen had been duly elected:

President.

HARRISON HAYTER.

Vice-Presidents.

Alfred Giles, M.P.
Sir Robert Rawlinson, K.C.B.
Sir Benjamin Baker, K.C.M.G., LL.D., F.R.S.
Sir James Nicholas Douglass, F.R.S.

Other Members of Council.

William Anderson, D.C.L., F.R.S.
John Wolfe Barry.
Alexander R. Binnie.
Edward Alfred Cowper.
Sir Douglas Fox.
J. C. Hawkshaw, M.A.
Charles Hawksley.
Sir Bradford Leslie, K.C.I.E.
George Fosbery Lyster.
James Mansergh.
Sir Guilford Lindsay Molesworth, K.C.I.E.
William Henry Preece, F.R.S.
Sir Edward James Reed, K.C.B., F.R.S., M.P.
William Shelford.
Francis William Webb.

Resolved,—That the thanks of the meeting be given to the Scrutineers, and that the Ballot-Papers be destroyed.

REPORT OF THE COUNCIL, Session 1891–92.

This Meeting has been convened, in terms of the By-Laws, to receive and deliberate upon the Report of the Council on the state of the Institution, and to elect the Council and Officers for the ensuing year.

The Objects of the Institution are so widely known, have been so frequently referred to, and appear to be so largely appreciated, that they may be passed over without comment. The Constitution has remained unchanged since the 2nd of December, 1878, when the class of Associates was divided into two groups, one being Civil Engineers to whom corporate privileges were granted and who were distinguished by the title of Associate Members, the other being non-corporate Associates, described as persons able, from their connection with Science or the Arts, or otherwise, to advance professional knowledge.

The Roll of the Institution.

The Council has carefully guarded the admission of new members to every class of the Institution, and the qualifications of all candidates have been subjected to rigid scrutiny. The aim the Council always has in view is, that the possession of the diploma of corporate membership of the Institution shall be evidence that its holder has had a sufficient training, and has shown that he has gained practical experience. It is believed that a strict enquiry into each candidate's career is better than any system of examination. The Council would again urge members not to attach their names to the recommendation of any one for election, or for transfer, unless thoroughly satisfied that the candidate is in all respects, professionally and socially, eligible. Members of Council have for some years declined to sign proposals for the transfer of Associate Members to the class of Member, because, under the By-laws, they are the sole arbiters and judges in the matter. This is not so in the case of applications for election, because, although the classification rests entirely with the Council, every such proposal is determined by ballot of the general body.

Although the increase in the Roll of the Institution for the year ending the 31st of March, 1892, was at the rate of $4\frac{1}{3}$ per cent. per annum only, as against 5 per cent. for the previous twelve months, it must not be inferred that there has been any decline in the number of candidates elected. As a matter of fact 366 names were added to the Register as against 354, so that the decreased percentage of gain must be attributed to the large number of deceases (85), which, with resignations and erasures, have involved the disappearance from the list of no less than 145 members. It must also be borne in mind that, as the gross total becomes larger, the annual additions cannot be expected to increase at the same percentage as in the past. This will be more fully appreciated on reference to the tabular statement given below. It is a matter of congratulation that out of 324 candidates elected into the Associate Member class as many as 106 were previously Students. Amongst the deceases will be noticed with great regret the names of two esteemed Past-Presidents, Sir John Hawkshaw and Sir John Coode, K.C.M.G., and of five Honorary Members. This loss to the latter class has been partially made good by the election of three distinguished men, Dr. Werner von Siemens, the eminent scientist of Berlin and the elder brother of the late Sir William Siemens; Field-Marshal Sir Lintorn Simmons, R.E., G.C.B., eminent as a military engineer, and from 1846 to 1849 so well known as an Inspector in the Railway Department

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—	April 1, 1890, to March 31, 1891.					April 1, 1891, to March 31, 1892.				
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Totals.
Numbers at commencement .	19	1,684	2,768	432	4,903	20	1,743	2,965	422	5,150
Transferred to Members	..	..	53	..		..	..	59	..	
Elections .	2	51	291	7	354	3	28	324	7	366
Restored to Register .	..	..	3	..		..	..	4	..	
Elected Honorary Members .	..	..	..	..	-107	..	..	..	1	-145
Associate elected Member .	..	..	..	1		..	..	..	1	
Deaths . .	1	31	17	10		5	40	27	13	
Resignations	..	7	8	6		..	6	10	10	
Erased . .	..	7	19	..	— 247	..	10	20	2	— 221
Numbers at termination	20	1,743	2,965	422	5,150	18	1,774	3,177	402	5,371

of the Board of Trade; and Sir George G. Stokes, Bart., M.P., late President of the Royal Society. On the 31st of March, 1891, there were on the books 5,150 members of all classes (omitting Students), as against 5,371 on the corresponding date this year; whilst, including Students, the respective numbers were 6,064 and 6,239.

The deceases were :—

Honorary Members.—Sir George Biddell Airy, K.C.B., M.A., D.C.L., F.R.SS. L. & E.; Jean Charles Adolphe Alphand; H.M. Dom Pedro II, Ex-Emperor of Brazil; H.R.H. the *Duke* of Clarence and Avondale, K.G.; and the *Duke* of Devonshire, K.G.

Members.—Henry John Card Anderson; William Bell; Stephen Charles Best; William Newsham Blair; Henry Bolden; Samuel Brown; John Cochrane; *Sir* John Coode, K.C.M.G. (*Past President*); William Janvrin du Port; George Fisher; William John Galwey; Richard Boxall Grantham; Francis Baker Hanna; William John Hardcastle, *Bey;* John Thornhill Harrison; *Sir* John Hawkshaw, F.R.SS. L. & E. (*Past President*); Henry Temple Humphreys; Hubert Laws; John Mackenzie; John Marley; William Mills; Alfred Penny; Loftus Perkins; Wilson Weatherley Phipson; William Coupar Rennie; Robert Richardson; Robert Riddell; William Booth Scott; Richard Sennett, Wh.Sc.; Charles Percy Bysshe Shelley; George Sibley, C.I.E.; Edward Slaughter; Hugh Smellie; John Taylor (Westminster); Benjamin Walker; Thomas Waring; Robert Watson; John Willet; Robert Stodart Wyld, Jun.; and Thomas Wynne.

Associate Members.—Arthur Joseph Edwin Arch; Arthur Turnour Atchison, M A.; John Baldwin; John Cameron; Gerrit Willem Camphuis; Alexander William Conquest; Joseph Prendergast Coy; John Cundy; Samuel Forbes Downing, M.A.; Thomas Duncan; Francis Gillham; Edward Dames Hamill; Harold Hayes Harker; Edmund Lincoln Harper; Edward Jackson Hawkins; Samuel Collett Homersham; William George Jones; Jorgen Daniel Larsen; Charles Edward Cage Montresor; James Michael Moore; John Lambe Rigden; John Henry Riley; Thomas William Stone; James John Talman; Edward Henry Thorman; George Winn Webb; and Henry Woolcock.

Associates.—James Binfield Bird; Henry James Castle; George Dyson; Thomas Henry Eagles, M.A.; Thomas Bland Garland; William Havard Hunter; John Jackson (Eastbourne); John William Miers; *Captain Sir* Henry Morland; Donald Nicoll; Jeremiah Ryan; *Major-General* Frederick Smith Stanton, R.E., *retired;* and Thomas Statter.

The resignations have been :—

Members.—Archibald Henry Constable; Edward Read Nelson Druce; William Evans; John Ward Girdlestone; John William Drinkwater Harrison; and Thomas Medcalf.

Associate Members.—Charles Dallas Alexander, M.A.; George William Heaton Armstrong; Harry Kenneth Austin; Charles William Bryden; Robert Ewing; Sir Malcolm Fraser, K.C.M.G.; Edgar Chichester Jones; John Edmund Phipps Lincké; John Stansfield-Brun; and Frederick Walsh.

Associates.—James Kenward; *Colonel* Eardley Maitland, C.B., R.A.; James Ball Mannix; Frederick Ernest Muntz, B.A.; George Robinson, R.N., *retired; Lieut.-Colonel* Charles Edward Shepherd, B.S.C.; *Sir* Thomas Raikes Thompson, *Bart.;* Oswald Turner; Thomas Debell Welsh; and the *Rev.* George Herbert West, D.D.

ADMISSION OF STUDENTS.

The total number of Students on the 31st of March, 1892, was 868, as against 914 at the corresponding period of last year. As will be seen on reference to the table below, this decrease is not due to any decline in the admissions, which, it is satisfactory to note, have amounted to 200, as against 166 for the previous twelve months, but, as previously stated, to an unusually large number having been elected Associate Members. Thus during the year 106 Students became Associate Members—nearly one-third of the total number elected—while, from deceases, resignations, and other causes, 140 names disappeared from the list. The Council feels justified, therefore, not only from the above facts, but from the account of the Students' Meetings and Visits to Works during the past Session, which will be found elsewhere in this Report, in regarding this class as in a flourishing condition. Not only have the admissions increased during the past year, but, by the working of the Special Regulations as to the educational qualifications of candidates, the professional character of the class has been greatly improved.

FINANCE.

The Statement of Accounts, duly verified and signed by the Auditors, is appended to this Report. During the financial year ending the 31st of March, 1892, the receipts were:—Income, £20,070 17*s.* 3*d.*; Capital, £5,186 7*s.*, including a bequest of £500

STUDENTS.

April 1, 1890 . . .			969
Admitted during the year	166		
Restored	2		
		168	
Elected Associate Members	85		
Resigned	24		
Deceased	8		
Erased	106		
		-223	
			-55
March 31, 1891 . .			914

April 1, 1891 . . .			914
Admitted during the year		200	
Elected Associate Members	106		
Resigned	25		
Deceased	1		
Erased	114		
		-246	
			-46
March 31, 1892 . .			868

under the will of Sir John Hawkshaw; Trust-Funds, £930 19*s.* 8*d.*; Capital Extraordinary, £251 5*s.*; making a total of £26,439 8*s.* 11*d.* as against £24,274 8*s.* 11*d.* for the previous twelve months. The Disbursements were:—General expenditure, £15,038 14*s.* 6*d.*; Capital, £7,497 5*s.* 3*d.*; Trust-Funds, £821 1*s.* 5*d.*; Capital Extraordinary, £1,612 13*s.* 9*d.*, together, £24,969 14*s.* 11*d.*, as against £23,351 1*s.* 9*d.* last year. The capital receipts were invested in Debenture Stocks of British railway companies of the nominal or par value of £7,000. Besides the investments on account of capital, a sum of £1,361 8*s.* 9*d.* was transferred from the yearly receipts to Capital Extraordinary, in connection with the purchase of the lease of No. 27, Great George Street, of which, having regard to the question of rebuilding, still under consideration, it was deemed advisable the Institution should become possessed. The balances at the beginning and at the end of the year were respectively £6,755 2*s.* 8*d.* and £8,224 16*s.* 8*d.*

The Trust-Funds administered by the Council have been augmented by the receipt of subscriptions to the amount of £510 on account of the "James Forrest Lectureship," to which reference was made in the Report of last year. That sum was invested in the purchase of £320 South Eastern Railway 5 per cent. Debenture Stock, bringing up the total of the Trust-Funds to £15,606 0*s.* 10*d.*

THE SESSION AND MEETINGS.

The Council has on several occasions alluded to the fact that, as the Corporation includes all classes of Civil Engineers who are eligible for admission under the By-Laws, it must be expected that the Minutes of Proceedings will be gradually modified and developed so as to meet the wants of its more diversified membership. Having regard to these considerations, the duty devolves upon the present governing body of indicating in what way the science of engineering has been dealt with during the past twelve months.

It will be found that in CONSTRUCTIVE ENGINEERING (which may be considered as synonymous with the popular but limited definition of "Civil" Engineering) five Papers have been read. Two of these, "The Bishop Rock Lighthouses" and "The Illumination by Gas of Tory Island Lighthouse," by Messrs. W. T. Douglass and D. C. Salmond, referred to sea-coast works of supreme importance to every maritime nation. The three communications on "Portland Cement" and on "Portland Cement Concrete," by Messrs. Bamber, Carey and Smith, which for convenience of discussion were grouped together, related to a material which is fast becoming indispensable to the constructive engineer.

A branch of the profession of the highest importance, having regard to its bearing on the health of towns and on sanitation generally, is MUNICIPAL ENGINEERING. Two Papers directly connected with this subject were submitted for discussion—namely, those on the "Sale of Water by Meter in Berlin," by Mr. Henry Gill, and on the "Sewage-Farms of Berlin," by Mr. H. A. Roechling. Both these communications bore witness to the advanced condition of sanitary matters in the capital of the German Empire, and to the praiseworthy determination of German engineers to remedy past neglect and to keep pace with the times. The elaborate Paper by Mr. Binnie on "Mean or Average Annual Rainfall" must also be classed with municipal engineering, as referring to one of the data upon which the waterworks engineer bases his calculations.

MINING AND METALLURGICAL ENGINEERING were represented by the Paper of Mr. A. H. Curtis on "Gold-Quartz Reduction." As the modern processes of ore-reduction are accomplished by the aid of machinery, the efficient conduct of the operations is directly dependent upon the engineer. From an economical point of view, also, any improved processes tending to increase the supply of gold, by preventing waste, are worthy of recognition and acknowledgment.

MECHANICAL ENGINEERING.—The memoir by Mr. Wilfrid Airy on "Weighing-Machines" opened up entirely new ground. Until the publication of this article no systematic investigation of the important considerations involved in the scientific construction of this class of machine had appeared in print. The Paper on "Petroleum-Engines," by Professor Unwin, was mainly an exhaustive study of a particular engine, probably more useful and instructive than a cursory description of many machines would have been.

ELECTRICAL ENGINEERING was represented by the Paper of Mr. Swinburne on "Electrical-Measuring Instruments," in which stress was laid on the fact that, electrical engineering having arrived at a position of great prominence, a complete change had been brought about in the instruments of measurement, which were no longer confined to the laboratory, but were turned out by the thousand for use in the workshop.

Many questions of importance which belong primarily to the domain of PHYSICS require to be attentively studied by the engineer. Especially is this the case in respect of the operations connected with the measurement of light and of heat. The Papers by Mr. Trotter on "The Distribution and Measurement of Illumination" and Professor Roberts-Austen on "The Measurement of High Temperatures," which concluded the Session, related to subjects that have not frequently been dealt with at the Institution, but which are of such growing importance that engineers cannot afford to ignore their scientific consideration. In Mr. Trotter's communication an attempt was made to estimate the practical effect of lighting upon the basis of predetermined contour lines of uniform illumination. To Professor Roberts-Austen it is only necessary to repeat the thanks of the Council for making public, through the medium of this Institution, his valuable investigations.

From the foregoing summary it will be seen that thirteen Papers were read during the Session, mostly on subjects of very considerable importance, as may be gathered from the long and animated discussions to which they gave rise.

To the Authors of some of these communications the Council has had pleasure in making the following awards out of the special Trust Funds bequeathed or assigned for the purpose:—a George Stephenson Medal and a Telford Premium to Mr. Alexander R. Binnie; Telford Medals and Premiums to Mr. A. P. Trotter and Mr. W. T. Douglass; and Telford Premiums to Messrs. H. A. Roechling, A. H. Curtis, W. Airy, H. Gill, and Professor W. C. Roberts-Austen.

Among the Papers which have been deemed suitable for printing, without being discussed, those by Mr. Francis Fox on "The Hawarden Bridge," and Mr. A. W. Szlumper on the "Widening and Improvement Works, London and South-Western Railway Metropolitan Extension," belong directly to Constructive Engineering. Closely related to this branch are the communications by Professor T. H. Beare on "The Building-Stones of Great Britain; their Crushing-Strength and other Properties;" by Mr. A. D. Stewart on "Stresses and Deflections in Braced Girders;" and by Mr. R. H. B. Downes on "Practical Astronomy as applied to Land Surveying."

The description of "The Nagpúr Waterworks Extension," by Mr. Edmund Penny, and of "The Southampton Waterworks," by Mr. William Matthews, affect the Municipal Engineer; while Mechanical and Electrical Engineering are respectively dealt with in the Papers by Professor W. C. Unwin on "The Transmission and Distribution of Power from Central Stations by Compressed Air," and by Dr. C. P. Sheibner on "The Florence and Fiesole Electric Railway."

In respect of these contributions Telford Medals and Telford Premiums have been awarded to Messrs. F. Fox and A. W. Szlumper, and Telford Premiums to Messrs. C. P. Sheibner, T. H. Beare, W. C. Unwin, E. Penny, A. D. Stewart, R. H. B. Downes, and W. Matthews.

The Howard Quinquennial Prize has been adjudged to Sir I. Lowthian Bell, Bart., F.R.S., M. Inst. C.E., for his treatise on "The Principles involved in the Manufacture of Iron and Steel."

The monthly Receptions by the President and Council, inaugurated last year, have been continued, five such gatherings having been held during the Session just concluded, on the fourth Tuesdays in the months of January, February, March, April, and May. The collections of models and instruments exhibited on these occasions have been generally interesting and instructive, but special mention should be made of those relating to Mining-Machinery, to Sea-Coast works, and to Climatology. The latter display, which formed the annual exhibition of the Royal Meteorological Society, served also to illustrate Mr. Binnie's Paper on "Rainfall," and, though perhaps appealing less to the engineer than to the meteorologist, was one of the best exhibitions of the kind yet held. The scientific instruments, mainly electrical, lent on other occasions also merit notice. The exhibition of a few selected specimens of the machines or engines described in a Paper greatly enhances the interest felt in it, and in that way stimulates discussion.

STUDENTS' MEETINGS AND VISITS TO WORKS.

It is with much pleasure that the Council records the work of the Student class during the past Session. In satisfactory contrast with last year, Papers were submitted in sufficient number and of sufficient merit to enable twelve Supplemental Meetings to be held, as nearly as possible on alternate Friday evenings. The average attendance was 42, or about 14 per cent. of the students residing in and around London. This is a decided improvement on recent years, and the Council would urge the members of this class to give in the future increasing evidence of interest by being present in still larger numbers at these meetings, and also at the visits to works. With regard to the latter the Council is aware that many Students find difficulty in obtaining leave of absence during the day, and it is only in rare instances that evening or Saturday afternoon visits can be arranged; still it is thought that, when members of the Institution are made acquainted with the object for which leave is sought, they will be glad to do all in their power to enable their pupils to enjoy the facilities afforded by the owners of works, most of which are only open to inspection by favour and as an act of courtesy. During the past Session there were eleven of these visits, the average attendance being 23.

The Papers read at the Supplemental Meetings showed, in nearly every case, evidence of having been prepared with care. Three, at least, were of high merit, and, with four others above the average, have been deemed worthy of publication, either in whole or in part, in the Minutes of Proceedings. Adopting the same general classification as for those read before the Institution, it will be found that of the Papers selected for award the bulk belong to mechanical engineering, namely, those by Mr. H. B. Ransom on "Fly-Wheels and Governors," Mr. R. J. Durley "On some forms of Petroleum-Engines;" and three having special reference to railway machinery, viz., by Mr. E. L. Hill on "The Speed and Power of Locomotive Engines;" Mr. G. H. Sheffield, "The Construction and Relative Efficiency of Locomotive-Boilers," and Mr. J. B. Ball, "A Description of the Works and Plant used in the Manufacture of Oil-Gas at the Holloway Works of the Great Northern Railway." Mining and metallurgical engineering produced one Paper, that by Mr. D. Carnegie on "The Manufacture of Forged Steel Projectiles;" while Electrical Engineering was represented by Mr. C. H. Wordingham's description of "Meters for Recording the Consumption of Electrical Energy."

The Council has had much pleasure in awarding to H. B. Ransom, for his Paper on "Fly-wheels and Governors," the Miller Scholarship of £40 per annum, tenable for three years; and Miller Prizes to C. H. Wordingham, E. L. Hill, D. Carnegie, G. H. Sheffield, J. B. Ball, and R. J. Durley.

In connection with the Students' Seventeenth Annual Dinner, held on the 13th of May, it was decided to arrange, for that and the previous days, two series of Special Visits to Works, which country students particularly were urged to attend, so that they might have an opportunity of meeting and becoming acquainted with their colleagues in London. The visits on the 12th of May were to the works of the Gas Light and Coke Company at Beckton, the London County Council's Sewage Mixing-tanks and Northern Outfall at Barking, the Peninsular and Oriental Steam Navigation Company's Ship "Oceana," and the Royal Victoria and Albert Docks; and on the following day to the Royal Arsenal at Woolwich, the works of the London Electric Supply Corporation at Deptford, and the Tower Bridge. The attendances were about 65 on the first day, and 95 on the second; and included 25 Students from various parts of the country, the local Associations at Manchester, Glasgow, Birmingham, and Newcastle-on-Tyne, being well represented, so that the object for which these visits were arranged was satisfactorily accomplished.

The Council learns with pleasure that the four local Associations above referred to, have done good work during the past Session. Such bodies, if properly managed, cannot fail to promote the interests of the Student class, and efforts are being made to establish similar Associations in all the large engineering centres of the kingdom, towards the promotion of which it is hoped that members of all classes will render willing assistance.

In concluding this section of the Report, the Council desires to place on record its opinion that the success of the past Session points to the fact that, while in the case of country Students local associations are undoubtedly valuable, the interests of the London Students are more efficiently promoted under the direct care of the Institution.

INDEX TO THE MINUTES OF PROCEEDINGS.

Fourteen years having elapsed since the issue of a General Index to the publications of the Institution, arrangements have been made for the preparation of a Subject-Index to the subsequent volumes of the Minutes of Proceedings, namely, vols. LIX to CX, the last volume for the Session just completed. The compilation of this work has been entrusted to Mr. Henry B. Wheatley, by whom the "Name-Index," forming the complement to the first Subject-Index, was prepared. The undertaking, which is of a laborious character, is actively proceeding, and it is hoped may be ready for the printer before the end of this year.

LIBRARY CATALOGUE.

For many years past the only catalogue of the Library has been that in manuscript, which is made up from day to day in order to keep pace with the growth of the collection. This catalogue, which is bound in three folio volumes, having become considerably worn, it was decided to have it printed, only a limited number of pages being entrusted to the printer at one time. It is not contemplated to issue a separate copy of the printed catalogue to each member of the Institution, but a sufficient number of copies will be printed to allow of a stock being kept for special purposes.

Portrait of Sir Joseph Bazalgette, C.B.

The collection of oil paintings of Past Presidents of the Institution has been augmented by the portrait of Sir Joseph Bazalgette, C.B., who occupied the chair in 1884. For this addition the Institution is indebted to Lady Bazalgette, to whom the Council has tendered its best thanks.

Other Societies and Lectures.

As representing the profession at large in this country, the Institution has always been willing to be of service to other Societies established for promoting special branches of engineering by according to such bodies the gratuitous use of its meeting-room and offices. In addition to those Societies which for many years past have been thus accommodated, the Association of Municipal Engineers and County Surveyors, the Gas Institute, the Federated Institution of Mining Engineers, and the Incorporated Institution of Gas Engineers, have held meetings at the house of the Institution during the past year.

On special grounds applications have been favourably entertained from the Royal Artillery Institution, and from the Middlesex County Council, the latter body needing such accommodation during the rebuilding of the Westminster Sessions House.

The Premises.

In the accounts will be noticed an item of £1,200 for the purchase of the remaining term of the lease of No. 27, Great George Street. When the question of rebuilding the premises on the present site came under the consideration of the Council elected last year, it was found that by reason of Nos. 26 and 27 Great George Street forming twin houses there would probably arise questions of ancient lights in respect of No. 27 if No. 26 were included in the rebuilding scheme. In order, therefore, to avoid litigation it was decided to purchase the lease in question, with a view of ultimately acquiring the freehold. The owners of No. 27, however, required for their rights a sum which was deemed exorbitant, being no less than the capital which, invested in Court of Chancery securities, would produce an income equal to that afforded by the premises as house property. Under these circumstances it has been determined to abandon the idea of purchasing the freehold of No. 27, and to surrender the premises on the expiration of the lease. An additional reason for this course is that since the purchase of the lease a Bill has been introduced into Parliament, which practically revives the powers of the Westminster (Parliament Street, etc.) Improvements Act of 1887. This Bill has passed the Lords' Committee, and will probably be read a third time in the House of Lords before Whitsuntide. The clauses in the former Act safeguarding the interests of the Institution have been inserted in the present Bill. It is believed that the rents of No. 27 will be sufficient to secure the Institution from any pecuniary loss, having regard to the fact that only 3 per cent. is obtainable for money as ordinarily invested.

VOLUNTEER ENGINEERS.

Understanding that there is a dearth of professional men in the Volunteer Regiments of the Royal Engineers, the Council ventures to express the hope that young Civil Engineers, whose education renders them peculiarly fitted to fill the vacancies and to be of service to their country, will come forward in larger numbers than appears to be the case at present, so as to prepare themselves by the necessary military training to give their aid in any national emergency.

ELECTION OF COUNCIL AND OFFICERS.

One of the purposes for which this meeting has been summoned is "to elect the Council and Officers for the ensuing year." To the regret of his colleagues, Mr. Berkley intimated that he did not desire to become a candidate for re-election as President for a second year. In accordance with the By-laws the senior Vice-

President, Mr. Harrison Hayter, has been nominated for that office, and Sir James Douglass has been chosen by ballot in the Council as a candidate for the vacancy in the list of Vice-Presidents. The addition of the names of Messrs. Richard Johnson and Alex. B. W. Kennedy to the list of last year, completes the statutory number of twenty-nine corporate members, submitted as the balloting-list for this election.

[Abstract of Receipts and Expenditure.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

£	*Dr.*	£.	s.	d.	£.	s.	d.	£.	s.	d.
	To Balance, April 1st, 1891, viz.:—									
	On Deposit				3,000	0	0			
	Cash in the hands of Treasurer				3,699	16	10			
	„ „ Secretary				55	5	10	6,755	2	8
	INCOME.									
	— Subscriptions:—									
	Arrears	607	15	6						
	Current	15,062	19	0						
	Advance	718	14	6	16,389	9	0			
	— Library Fund				163	4	0			
	— Minutes of Proceedings:—Repayment for Binding, &c.				304	10	3			
	— Dividends: 1 year on									
£	*Institution Dividends.*									
6,000	2¾% Consols	160	12	0						
6,000	Metropolitan Board of Works 3½% Stock	204	15	0						
6,000	Great Eastern Railway 4% Debenture Stock	234	0	0						
8,000	Great Northern 3% Debenture Stock	234	0	0						
6,000	Great Western 4% Debenture Stock	234	0	0						
3,000	Lancs. and Yorks. Ditto	117	0	0						
8,000	London & N. W. Ditto	312	0	0						
6,000	Midland Ry. 3% Ditto	175	10	0						
3,000	North Eastern 4% Ditto	117	0	0						
	NEW PURCHASES.									
6,000	London & South W. Ry. 3% Debenture Stock (6 months on £3,000	43	17	6						
1,000	North Eastern Railway 4% Debenture Stock	0	0	0	1,832	14	6			
£59,000	Total nominal or par value.									
	Whitworth Legacy.									
£1,400	5% Debenture Stock in Sir Joseph Whitworth & Co., Ltd.	68	5	0						
4,000	Four hundred £10 shares in Ditto	600	0	0	668	5	0			
£5,400	Total nominal or par value.									
	— Rents—No. 26, Great George Street				650	12	6			
	— Interest on Deposit				62	2	0	20,070	17	3
	Carried forward							£26,825	19	11

from the 1st APRIL, 1891, *to the* 31st MARCH, 1892.

EXPENDITURE.

Cr.

General Expenditure.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
By House and Establishment Charges:—									
Repairs:— Nos. 24 & 25 Great George Street	737	11	5						
No. 26 Gt. George St.	20	2	5						
				757	13	10			
Rates and Taxes:—									
Nos. 24 & 25 Great George Street	659	16	8						
No. 26 Gt. George St.	128	19	9						
				788	16	5			
Insurance:—Nos. 24 & 25 Great George Street	46	19	6						
No. 26 Gt. George St.	5	1	3						
				52	0	9			
Rent of Telephone				22	2	0			
Fixtures and Furniture				126	0	8			
Lighting and Warming:—									
Nos. 24 & 25 Great George Street	195	4	2						
No. 26 Gt. George St.	18	12	9						
				213	16	11			
Refreshments at Meetings				57	1	7			
Assistance at Meetings				33	1	6			
Monthly Receptions				201	16	9			
Students' Meetings				56	11	4			
Household Expenses				216	17	10			
							2,525	19	7
— Postages, Telegrams, and Parcels				281	9	5			
— Stationery and Printing				687	0	10			
— Diplomas				69	19	6			
— Annual Dinner (balance of 1891 and part 1892)				301	16	2			
							1,340	5	11
— Salaries				2,275	0	0			
— Clerks, Messengers, and Housekeeper				864	10	10			
— Retiring Allowance to late Librarian				200	0	0			
— Donations to late Housekeeper and Messenger				82	0	0			
							3,421	10	10
— Library:—Books				350	7	6			
Periodicals				65	5	0			
Binding				173	17	11			
							589	10	5
— Publications:—									
"Minutes of Proceedings," Vols. civ., cv., cvi. and cvii.				6,759	11	11			
Charter, By-Laws, and Lists of Members				254	12	1			
"Engineering Education"				109	18	3			
							7,124	2	3
— Surveyor's Fee, *re* Appeal against Assessments							37	5	6
Carried forward							£15,038	14	6

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*continued.*

Dr.				£. s. d.
	Brought forward			26,825 19 11
	CAPITAL.			
	To Admission-Fees		3,947 9 0	
	— Life-Compositions		738 18 0	
	— Hawkshaw Legacy		500 0 0	
				5,186 7 0
	TRUST-FUNDS.			
	Telford Fund.	£. s. d.	£. s. d.	
	To Dividends:—1 year on			
£. s. d.				
5,439 11 0	2¾% Consols	146 16 0		
3,299 2 0	Ditto (Unexpended Dividends)	88 4 0		
£8,738 13 0			235 0 0	
	Manby Donation.			
£250 0 0	Great Eastern Ry. 4% Debenture Stock		9 15 0	
	Miller Fund.			
3,125 0 0	2¾% Consols	83 9 8		
2,004 17 5	Ditto (Unexpended Dividends)	53 12 0		
£5,129 17 5			137 1 8	
	Howard Bequest.			
£551 14 6	2¾ % Consols		14 18 4	
	Trevithick Memorial.			
£103 0 0	2¾ % Consols		2 14 8	
	Crampton Bequest.			
£512 15 11	2¾% Consols		13 14 0	
	James Forrest Lectureship.			
	— Subscriptions	510 0 0		
£320 0 0	South Eastern Ry 5% Debenture Stock, 6 Months	7 16 0		
			517 16 0	
				930 19 8
				£32,943 6 7

EXPENDITURE—*continued.*

Cr.							£.	s.	d.
Brought forward							15,038	14	6
CAPITAL.									
By Purchase of									
£6,000 L. & S. W. Ry. 3 % Debenture Stock . .				6,158	14	9			
£1,000 N. E. Ry. 4 % Ditto				1,338	10	6			
							7,497	5	3
£7,000 Total nominal or par value.									
TRUST-FUNDS.									
By Telford Premiums	137	7	3						
— Telford Medals	9	0	0						
				146	7	3			
— Miller Scholarships	80	0	0						
— Miller Prizes	85	5	8						
				165	5	8			
— James Forrest Lectureship:—									
Purchase of £320 South Eastern Ry. 5 % Debenture Stock . .				509	8	6			
							821	1	5
— Balance, March 31st, 1892:—									
On deposit				7,000	0	0			
Cash in the hands of the Treasurer				1,215	4	10			
” ” Secretary				9	11	10			
							8,224	16	8
							31,581	17	10
— Transferred to Debit of Capital Expenditure—Extraordinary							1,361	8	9
							£32,943	6	7

ABSTRACT OF RECEIPTS *and* EXPENDITURE

Dr.

RECEIPTS—*continued.*

CAPITAL RECEIPTS—EXTRAORDINARY.

	£	*s.*	*d.*	£	*s.*	*d.*
To Transferred from Yearly Receipts, viz. :—				1,361	8	9
— Rents :—No. 27 Great George Street	235	0	0			
Stables in Tufton Street (one quarter)	16	5	0			
				251	5	0
				£1,612	13	9

SUMMARY OF INVESTMENTS.

	£.	*s.*	*d.*	£.	*s.*	*d.*
INSTITUTION INVESTMENTS				59,000	0	0
FREEHOLDS OF NOS. 24, 25 & 26 GREAT GEORGE STREET				40,000	0	0
WHITWORTH LEGACY :—400 SHARES OF £10, AND £1,400 5 % DEBENTURE STOCK IN THE FIRM OF SIR JOSEPH WHITWORTH AND CO., Ltd.				5,400	0	0
TRUST-FUNDS INVESTMENTS :—						
Telford Fund	8,738	13	0			
Manby Donation	250	0	0			
Miller Fund	5,129	17	5			
Howard Bequest	551	14	6			
Trevithick Memorial	103	0	0			
Crampton Bequest	512	15	11			
James Forrest Lectureship	320	0	0			
				15,606	0	10
				£120,006	0	10

from the 1st APRIL, 1891, *to the* 31st MARCH, 1892.

Cr. EXPENDITURE—*continued.*

CAPITAL EXPENDITURE—EXTRAORDINARY.

	£	s.	d.
By Purchase of Leasehold of No. 27 Great George Street	1,200	0	0
— Rent of Ditto (6 months)	300	0	0
— Repairs of Ditto	8	1	8
— Rates and taxes of Ditto	81	8	0
— Insurance of Ditto	6	16	6
— Lighting of Ditto	1	12	1
— Building Question (Lithographers' charges for plans)	14	15	6
	£1,612	13	9

Examined with the Books and found correct.

(Signed) WM. MATTHEWS, F. S. COURTNEY } *Auditors.*

JAMES FORREST, *Secretary.*
17*th May*, 1892.

PREMIUMS AWARDED.

SESSION 1891–92.

THE Council of the Institution of Civil Engineers has awarded the HOWARD QUINQUENNIAL PRIZE to Sir Isaac Lowthian Bell, Bart., F.R.S., M. Inst. C.E., for his treatise on "The Principles involved in the Manufacture of Iron and Steel."

The following is a detailed list of the awards made for Original Communications submitted during the past Session:—

FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A George Stephenson Medal and a Telford Premium to Alexander Richardson Binnie,[1] M. Inst. C.E., for his Paper "On Mean or Average Annual Rainfall, and the Fluctuations to which it is subject."
2. A Telford Medal and a Telford Premium to Alexander Pelham Trotter, B.A., Assoc. M. Inst. C.E., for his Paper on "The Distribution and Measurement of Illumination."
3. A Telford Medal and a Telford Premium to William Tregarthen Douglass,[2] A.K.C., M. Inst. C.E., for his account of "The Bishop Rock Lighthouses."
4. A Telford Premium to Herman Alfred Roechling, Assoc. M. Inst. C.E., for his Paper on "The Sewage-Farms of Berlin."
5. A Telford Premium to Alfred Harper Curtis, B.A., Assoc. M. Inst. C.E., for his Paper on "Gold-Quartz Reduction."
6. A Telford Premium to Wilfrid Airy,[3] B.A., M. Inst. C.E., for his Paper "On Weighing-Machines."
7. A Telford Premium to Henry Gill, M. Inst. C.E., for his account of "The Sale of Water by Meter in Berlin."
8. A Telford Premium to Professor William Chandler Roberts-Austen, C.B., F.R.S., for his Paper "On the Measurement of High Temperatures."

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[1] Has previously received a Telford Medal and a Telford Premium.

[2] Has previously received a Telford Premium.

[3] Has previously received Telford and Manby Premiums.

FOR PAPERS PRINTED IN THE PROCEEDINGS WITHOUT BEING DISCUSSED.

1. A Telford Medal and a Telford Premium to Francis Fox,[1] M. Inst. C.E., for his account of "The Hawarden Bridge."
2. A Telford Medal and a Telford Premium to Alfred Weeks Szlumper, M. Inst. C.E., for his description of the "Widening and Improvement Works, London and South-Western Railway, Metropolitan Extension."
3. A Telford Premium to Charles Preller Sheibner,[2] Ph.D., Assoc. M. Inst. C.E., for his Paper on "The Florence and Fiesole Electric Railway."
4. A Telford Premium to Professor Thomas Hudson Beare, B.A., B.Sc., F.R.S.E., Assoc. M. Inst. C.E., for his Paper on "The Building-Stones of Great Britain; their Crushing Strengths and other Properties."
5. A Telford Premium to Professor William Cawthorne Unwin,[3] B.Sc., F.R.S., M. Inst. C.E., for his Paper on "The Transmission and Distribution of Power from Central Stations by Compressed Air."
6. A Telford Premium to Edmund Penny, M. Inst. C.E., for his account of "The Nagpúr Waterworks Extension."
7. A Telford Premium to Allan Duncan Stewart, M. Inst. C.E., for his Paper on "Stresses and Deflections in Braced Girders."
8. A Telford Premium to Robert Henry Burnside Downes, Assoc. M. Inst. C.E., for his Paper on "Practical Astronomy as Applied to Land Surveying."
9. A Telford Premium to William Matthews, M. Inst. C.E. (of Southampton), for his description of "The Southampton Waterworks."

FOR PAPERS READ AT THE SUPPLEMENTAL MEETINGS OF STUDENTS.

1. The Miller Scholarship to Herbert Byrom Ransom,[4] Stud. Inst. C.E., for his Paper on "Fly-Wheels and Governors."
2. A Miller Prize[4] to Charles Henry Wordingham, A.K.C., Stud. Inst. C.E.,[5] for his Paper on "Meters for Recording the Consumption of Electrical Energy."

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[1] Has previously received a George Stephenson Medal and a Telford Premium.

[2] Has previously received a Telford Premium.

[3] Has previously received Telford and Watt Medals and Telford Premiums.

[4] Has previously received a Miller Prize.

[5] Has since been elected an Associate Member.

3. A Miller Prize to Edmund Lewin Hill,[1] Stud. Inst. C.E., for his Paper on "The Speed and Power of Locomotives."
4. A Miller Prize to David Carnegie, Stud. Inst. C.E., for his account of "The Manufacture of Forged Steel Projectiles."
5. A Miller Prize to George Harrison Sheffield,[1] Stud. Inst. C.E., for his Paper on "The Construction and Relative Efficiency of Locomotive Boilers."
6. A Miller Prize to James Benjamin Ball, Stud. Inst. C.E., for his description of "The Works and Plant used in the Manufacture of Oil-Gas at the Holloway Works of the Great Northern Railway."
7. A Miller Prize to Richard John Durley, B.Sc., Stud. Inst. C.E., for his Paper "On some Forms of Petroleum-Engines."

⁂ It has been determined to print all the above Students' Papers, either in whole or in part, in the Minutes of Proceedings.

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[1] Has previously received a Miller Prize.

SUBJECTS FOR PAPERS.

SESSION 1892–93.

THE COUNCIL of the Institution of Civil Engineers invites Original Communications on the Subjects included in the following List, as well as on any other questions of professional interest. This list is to be taken merely as suggestive, and not in any sense as exhaustive. For approved Papers the Council has the power to award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The TELFORD FUND, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces £235 annually.

2. The MANBY DONATION, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The MILLER FUND, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises £140 per annum. Out of this Fund the Council has established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and is prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years. No Paper will be received from a Student in competition for the Miller Scholarship and the Miller Prizes when he has become qualified by age, viz. twenty-five years, for election into the Corporation.

4. The HOWARD BEQUEST, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to nearly

£15. It has been arranged to award this prize every five years, commencing from 1877. The next award will therefore be made in 1897.

5. The CRAMPTON BEQUEST of £500, free of legacy duty, has been invested in the purchase of £512 15*s.* 11*d.* 2¾ per cent. consols, and the income arising therefrom is now £13 15*s.* This trust is for the purpose of founding "a Prize to be called the 'Crampton Prize,' so that the interest of the said legacy shall be annually expended in a medal or books or otherwise . . . . for presentation to the Author of the best Paper on 'The Construction, Ventilation and Working of Tunnels of Considerable Length,' or, failing that then on any other subject that may be selected."

6. The balance of the TREVITHICK MEMORIAL FUND, amounting to £100 0*s.* 9*d.*, has been accepted for a periodical Premium to be called after Richard Trevithick. This sum has been placed in £103 2¾ per cent. consols, upon which the interest is £2 15*s.* a year.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the premiums no distinction will be made between essays received from members of the Institution or strangers, whether Natives or Foreigners, except in the cases of the Miller and the Howard bequests, which are limited by the donors.

LIST.

1. Standard Forms of Tests for Materials used in Engineering Construction.
2. The Methods and Cost of Converting Limestones into Lime.
3. The Design and Construction of Railway Passenger-Carriages, having reference to (*a*) strength and safety; (*b*) ease and smoothness of motion; (*c*) durability; (*d*) moderate dead-weight; (*e*) facility for entrance and exit; (*f*) lavatory accommodation; (*g*) provision for refreshments; and (*h*) sleeping arrangements.
4. The Cost of Working Electrical Tramways, taking account of interest on capital, and of a sinking fund for depreciation.
5. Ship Canals, and the Canalization of Rivers.
6. The Design and Construction of Ship Railways.
7. The Failures of Reservoir Embankments and Dams, and the Causes to which they may be ascribed, with suggestions for avoiding or remedying them.

8. The Disposal of Town Refuse by Burning, and the application of the heat thereby generated.
9. The Action of Weirs in times of Flood.
10. The Working of Inclined Retorts in Gasworks.
11. The Design and Construction of Modern Gas-holders of large size.
12. The Carburetting of Gases for Illuminating-purposes.
13. The most suitable form of Electric-Light Mains, having regard to durability, economy of conducting-material, and facility for making and laying house-connections.
14. The Risks of Electric Lighting to life and property, with the means to be taken to prevent or lessen them.
15. Plant for the Construction of Sea-works.
16. The Methods of and the Machinery for Tunnelling.
17. The various Systems of Mechanical Ventilation for Mines, Long Tunnels, Underground Railways, Sewers, &c.
18. The Design of Lofty Iron and Steel Structures.
19. The Laying-out of Engineering Workshops.
20. Modern Machine Tools and Workshop Appliances.
21. The Continuous Running of Steam and other Engines, with details of construction.
22. The best Arrangement of Engine for any given Electric-Light Station.
23. The various Systems of utilizing Compressed Air, Water, and Liquefied Gases for Motive-Power.
24. The recent developments of Mechanical Refrigeration.
25. Coal Shipping and Discharging Apparatus.
26. The Method of Trans-shipping Grain, and its classification and storage in Granaries.
27. The Structural and Other Defects of Iron and Steel Ships—and their causes.
28. The most recent types of (*a*) Passenger- and Mail-Steamers; (*b*) Cargo-Steamers; (*c*) War-Ships, and (*d*) Ferry-Steamers.
29. The Comparative Efficiency of different Types of Marine Engines.
30. Electrical Motors for (*a*) Inland Navigation; (*b*) Ocean Vessels.
31. Mechanical Propulsion for Life-boats and for small undecked vessels.
32. The Raising of Wrecks, with a description of the Plant Employed.
33. Mining-Operations—including the Sinking and Timbering of Shafts, fixing pumps, &c.

34. Coal-winning in seams situated at great depths below the surface.
35. The Surface-arrangements of Collieries; including those for banking, cleaning, sorting, screening, and shipping the Coal.
36. The best means of Utilizing the Slack of Non-caking Coal, including Briquette-making.
37. Recent Improvements in Pumping-Machinery.
38. Quarrying-Operations and the Plant Employed.
39. Recent Blast-Furnace Appliances, with reference to temperature and pressure of blast, &c.
40. The Modern Practice in the Manufacture of Finished Steel, having regard to increase of output and diminution of cost.
41. The Present Position of the Manufacture of Basic Steel.
42. The Manufacture of Aluminium and its Alloys.
43. The Influence of the Minute Admixture of Metals on the properties of Metallic Alloys for Engineering Uses.
44. The Concentration and Sizing of Crushed Ore and other materials.
45. Tin-Dressing as practised in Cornwall.
46. The Manufacture of Lead and the Extraction of Silver.
47. Smelting-processes as applied to the Extraction of Precious Metals from their ores.
48. The treatment of Gold and Silver Ores in the United States.
49. The Electro-deposition of Copper.
50. On the application of Water Power and its Transmission to a distance by Electricity.
51. The Design of Electric Locomotives.
52. The Practical Working of Multiphase Alternating-Current Motors.
53. The Design and Manufacture of Small Arms and of Quick-firing Ordnance.

Instructions for Preparing Communications.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1,500 words in length.

Illustrations, when necessary, should be drawn on tracing-paper, to as small a scale as is consistent with distinctness, but in no case should any Fig. exceed 6½ inches in height. When an illustrated communication is accepted for reading, a series of Diagrams will be required sufficiently large and boldly drawn to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, cannot be accepted by this Institution.

The Communications must be forwarded to the Secretary of the Institution, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it may be dealt with in the succeeding one.

William Pole, *Honorary Secretary*,
James Forrest, *Secretary*.

The Institution of Civil Engineers,
25, *Great George Street*, *Westminster*, *S.W.*
August, 1892.

Excerpt By-Laws, Section XV., Clause 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

Notice.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had premiums awarded to them, the Authors have advanced somewhat doubtful theories, or have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat that the Institution as a body must not be considered responsible either for the statements made, or for the opinions expressed in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS.

RECEIVED BETWEEN APRIL 1, 1891, AND MARCH 31, 1892.

AUTHORS.

Airy, W. No. 2,574.—On Weighing-Machines. With 42 Illustrations. (Vol. cviii., p. 2.)

Andrews, T. No. 2,543.—Effect of Temperature on the Strength of Railway Axles. Part III. With 4 Photographs of fractures. (Vol. cv., p. 161.)

Bamber, H. K. No. 2,556.—The Manufacture of Transverse Steel Sleepers of the Inseparable Clip Type, for Permanent-Way. With 15 Tracings. (Vol. cviii., p. 338.)

Barlow, C. No. 2,605.—The Tower Subway. With a Sheet of Illustrations.

Beare, Professor T. H. No. 2,559.—Building-Stones of Great Britain—their Crushing Strength and other Properties. With Tables and Appendix, 9 Drawings and 4 Photographs. (Vol. cvii., p. 341.)

Berrington, R. E. W. No. 2,576.—Wolverhampton Sewerage Works. With a Plan. (*Post*, p. 289.)

Binnie, A. R. No. 2,591.—On Mean or Average Annual Rainfall, and the Fluctuations to which it is subject. With 11 Tables and 1 Diagram. (Vol. cix., p. 89.)

Boyd, R. N. No. 2,588.—Deep Boring at Freistadt, near Teschen, Austrian Silesia. With 6 Drawings.

Bruce, A. F. No. 2,615.—The Rosario Water-works. With an Appendix, 2 Tracings and 6 Indicator Figs. (Vol. cviii., p. 334.)

Burgess, F. C. B. No. 2,624.—On the Design and Construction of Railway Passenger-Carriages. With 2 Tracings.

Burman, E. S. No. 2,604.—The Disposal of Abattoir Refuse by Desiccation. With 2 Tracings and an Abstract.

Cardew, J. H. No. 2,579.—The Alignment of the Bondi Sewer Tunnel, Sydney, New South Wales. With 3 Drawings and 1 Photograph.

Cockrill, J. W. No. 2,603.—The Use of Sea-Water for Street-watering, Sewer-flushing, and the other purposes required by Sanitary Authorities. With 3 Drawings and an Abstract. (*Post*, p. 343.)

AUTHORS.

Colson, C., and Colson, C. H. No. 2,600.—Malta Dockyard Extension. With Appendixes, 8 Tracings, and 14 Photographs.

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Dowson, J. E. No. 2,620.—Gas-Power for Electric Lighting.

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Fox, F. (1870). No. 2,565.—The Hawarden Bridge. With 14 Drawings and 2 Photographs. (Vol. cviii., p. 304.)

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Jackson, G. F. No. 2,575.—Iron and Steel Bridges on the Buenos Ayres and Valparaiso Transandine Railway. With 3 Specifications and 19 Drawings. (Vol. cix., p. 312.)

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Kühl, C. H. L. No. 2,549.—The Sulina Branch of the Danube. With 36 Illustrations. Vol. cvi., p. 238.)

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Matheson, H. C. No. 2,595.—Railways in China. With 2 Maps. (Vol. cix., p. 322.)

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O'Brien, G. No. 2,610.—On Certain Climatic Phenomena of the Northern Coast of the Republic of Chile. (Vol. cix., p. 301.)

AUTHORS.

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Stilwell, A. W. No. 2,590*a*.—The Water Supply of Riverina, New South Wales.

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Trotter, A. P. No. 2,619.—The Distribution and Measurement of Illumination. With 30 Figs. (*Ante*, p. 69.)

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"Contract Journal, The."
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Cornell University.
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Craven, A. W.
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Cuningham, W. M.
"Czasopismo Techniczne."

D.

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E.

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Edwards, F. G.
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"Electrical Engineer, The."
Electrical Purification Company.
"Électricien, L'. Revue Internationale de l'Électricité et de ses Applications."
"Electricity."
"Engineer, The."
"Engineering."
Engineering Association of New South Wales.
"Engineering News."
"Engineering Record, Building Record, and Sanitary Engineer."
Engineers Club of Philadelphia.
Entomological Society of London.
Ewing, J. A.

F.

Fanning, J. F.
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T.

Tanabe, Prof. S., M.E.
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"Travelers' Official Guide o the Railway and Steam Navigation Lines in the United States and Canada."
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Trinity University, Toronto.

U.

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World's Columbian Exposition, The.
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Zech et Fils.
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SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2563.*)

"Nágpúr Waterworks Extension."

By EDMUND PENNY, M. Inst. C.E.

MR. BINNIE's gravitation scheme for the native city of Nágpúr was completed in 1873, and was fully described in the Proceedings.[1] It was, however, limited in application; the higher parts of the city could not be supplied through want of sufficient head; the civil station, with its large population (now amounting to 13,000) was not included in the project, but was entirely dependent on wells, an unreliable source of supply; and matters were brought to a crisis in 1887, when almost every well failed and a severe outbreak of cholera occurred. The extension of the water-supply to the whole population was then seriously considered, and in 1889 a project was matured for the supply of the civil station and bazaars, the higher parts of the city, and the requirements of the Bengal Nágpúr Railway. In all, the daily wants of 44,000 people, and the requirements of the Bengal Nágpúr Railway, were provided for, at an estimated cost of 3 lacs of rupees.

The requirements were met from the existing reservoir at Ambajheri, the impounding capacity of which was slightly increased, so as to supply all additional demands and retain a reserve of 100,000,000 cubic feet at the end of an average season. The supply is drawn from the 13-inch city main at a point 2½ miles from the reservoir, and is run during the night into a large covered underground cistern holding nearly one-and-a-half day's supply. From this it is pumped a distance of 1½ mile into a covered service-reservoir situated on high ground, and distributed over the high-level area by gravitation.

The works comprised the following items:—

(i.) Raising and lengthening the old waste-weir; (ii.) branch pipe to the pumping-reservoir; (iii.) pumping-reservoir, with engine-house and staff-quarters; (iv.) duplicate steam-pumps and boilers; (v.) rising-main; (vi.) service-reservoir; (vii.) distribution system.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 1 *et seq.*

and the works were opened by the Chief Commissioner, Central Provinces, in August, 1890. The actual cost was Rs.303,552. The works were designed and executed by Mr. E. Penny, M. Inst. C.E., Executive Engineer, Nágpúr Division, under the advice and superintendence of Mr. J. H. Glass, M. Inst. C.E., C.I.E., Superintending Engineer, Central Provinces; Mr. J. Williamson, Sub-Engineer, being in charge.

TOTAL ESTIMATED CONSUMPTION AND CAPABILITIES OF THE WORKS.

The daily requirements for the new High-Level Extension are the following:—

	Gallons.
One thousand two hundred Europeans at 30 gallons per head	= 36,000
Forty-two thousand eight hundred natives at 8 gallons per head (including 25 per cent. to the city population)	= 342,400
Bengal Nágpúr Railway Co.	= 60,000
Maximum daily demand in twelve hours	= 438,400

= 70,144 cubic feet.

The records of the Nágpúr Waterworks for the past fifteen years show that the longest interval between the rains was 295 days, the average being 256 days (Appendix, Table II). If 300 days be taken as the longest interval during which the reservoir-level is affected by the draught, the total consumption to be allowed for is

$$70,144 \times 300 = 21,000,000 \text{ cubic feet.}$$

The zero on the reservoir gauge is at 1,014·7 feet above datum, the lowest sluice-sill level is at 1,009·7 feet, being 1 foot above the top of the outlet-pipe in the straining-chamber, and 5 feet above the floor-level. The zero point is taken at 1,014·7 feet because it is not advisable to draw below this level, as the tank, being shallow, would foul rapidly.

It was one of the original rules that, in order to guard against deficient rainfall, the quantity of water in the reservoir should not be allowed in one season to fall below 11·5 feet on the gauge; at which level the quantity in the reservoir is 100,000,000 cubic feet (Appendix, Table I).

		Million Cubic Feet.
At weir-crest level (1.036·0), or 21·3 feet on the gauge, the reservoir-capacity	=	238
At 11·5 on the gauge the reservoir-capacity . .	=	100
Balance above 11·5 feet	=	138

The greatest consumption from all sources in any one year up to 1888 has been 116,000,000 cubic feet; so that the least available balance to meet all contingencies has been 122,000,000; and the balance above the limiting height of 11·5 feet, 22,000,000 cubic feet. The increased consumption in the new scheme is 21,000,000 cubic feet; but, in order to meet the natural increase in the city consumption, and still to keep the low-water level above the limit of 11·5 feet on the gauge, it was considered advisable to add another foot to the waste-weir level, and so increase the reservoir-capacity by 15,000,000 cubic feet. The full capacity of the reservoir, with 1 foot added to the weir, is 253,000,000 cubic feet; allowing for city consumption 130,000,000, and for the new scheme 21,000,000, the total consumption would be 151,000,000, and the balance in the reservoir 102,000,000 cubic feet; hence the water-level will not fall below 11·5 feet on the gauge. The extra 15,000,000 cubic feet impounded by raising the weir-level 1 foot, is equivalent to a full month's supply at the beginning of the hot weather.

The following Table shows the average monthly consumption for the five years ending 1887 during the seven dry months, the increased consumption as the hot weather approaches being very marked.

Month.	Consumption in Cubic Feet.	Fall of Reservoir-Water Level.
		Feet.
November	10,901,200	0·76
December	9,750,800	0·64
January	9,931,300	0·65
February	11,489,200	0·72
March	14,701,000	0·99
April	16,278,000	1·22
May	19,531,000	1·33

Having shown that if 15,000,000 additional cubic feet were impounded, all requirements could be met and a good balance left in the reservoir; it was necessary to prove that the drainage-area would supply this extra quantity, and that the reservoir would fill to the new weir-level. The drainage-area is 6·6 square miles, and the reservoir-area ½ square mile, or one-twelfth of the drainage-area. Dealing with averages alone, the records of thirty years give an average monsoon-rainfall of 39·8 inches. Those of the past eighteen years, during which period the reservoir has been in use, show that it fills with an average fall of 23·3 inches (Appendix, Table III). This rainfall is spread on an average over forty-six days, and 23 per cent. of it is impounded from the drainage-area alone. Of the total average monsoon-rainfall of 39·8 inches, an average of 23·3 inches, or 58·5 per cent., suffices for absorption and compensation to the reservoir, and 41·5 per cent. is absorbed and runs to waste. In no case as yet has the rainfall failed to fill the reservoir. There is thus ample water obtained from the rainfall over the drainage-area to supply all demands.

The years of lowest rainfall were 1873, 1880, 1888, when a total rainfall of 24·26, 38·45, and 31·88 inches were recorded, spread over 90, 88, and 85 days respectively. The percentages impounded in these cases were respectively only 15, 13, and 14, and it required practically the whole rainfall for absorption and compensation; but in no case has the rainfall of two consecutive years proved insufficient.

When the reservoir was under construction in 1872, a series of experiments was made to arrive at the average quantity of water discharged from the drainage-area. The conclusions arrived at were,—that in an average season's fall of 37·52 inches, 38 per cent. might be expected to be impounded; and in a minimum year of 19·28 inches, about 15·5 per cent.[1] The approximate correctness of this estimate is fully borne out by the records of the past eighteen years; the average showing 23 per cent. impounded from 23·3 inches of rainfall.

It may be observed from Table III, that there are three series of minimum years, the averages of which are: rainfall 25·6 inches; percentage impounded 20·3; so that for a minimum discharge of three indifferent seasons, a smaller percentage must be taken than appears from the averages considered.

RAISING AND LENGTHENING THE OLD WEIR.

The old weir was 200 feet long, the crest being 6 feet below the top of the bank. It was designed to discharge 197,826 cubic feet per minute with a head of 2 feet 9$\frac{3}{8}$ inches—this being equivalent to a run-off of 1 inch of rain per hour from the catchment-area. By raising the crest 1 foot and lengthening the weir 257 feet, thus giving it a total length of 457 feet, a discharge of 276,713 cubic feet per minute could be obtained with a limiting head of 2 feet. This alteration was carried out, and the escape-channel widened in proportion.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 13.

The capabilities of the present weir are to dispose safely of 2$\frac{1}{2}$ inches discharge of rain in the first hour, and of 1 inch per hour in succeeding hours, when flowing full with a 2-feet head.

The old weir was concave in plan towards the reservoir, and 200 feet long on the curve. In order to minimise the quantity of excavation in the channel, the lengthening was effected by continuing the curve in the reverse direction at both ends. The plan and details of this work are shown in Figs. 1 and 2, Plate 1. On the south side it was extended 180 feet, and on the north side 77 feet. The material excavated in the channel was 1,061,305 cubic feet of soft disintegrated trap; the cost of this was Rs.14,593. The cost of raising and lengthening the weir, including the necessary side training-walls and some concrete and rubble masonry in some soft places below the fall, was Rs.7,876; the total cost for the weir and channel being Rs.22,469. The extra quantity of water impounded in the reservoir by raising the weir 1 foot, is 15,500,000 cubic feet, so that the cost per 1,000,000 cubic feet was Rs.1,449. The length of the new weir, extended and raised, is 257 feet; and 200 feet of the old weir was raised. The cost per lineal foot of the weir and return-walls was therefore Rs.17·2.

SUPPLY TO THE PUMPING-RESERVOIR.

To fill the reservoir and obtain water for pumping, two courses were open, viz., either to lay a separate main to Ambajheri, a distance of 4,700 yards, or to make use of the existing 13-inch pipe and merely lead a branch from it. There can be no doubt as to which would be the more thorough and efficient course; since drawing from the existing main must of necessity affect the pressure in the city. The cost of a separate 12-inch main would be about Rs.70,000. A 13-inch branch from the nearest point of the main to the pumping-reservoir would cost under Rs.5,000. It was therefore decided, for financial reasons alone, to utilize the existing main as far as possible, and to put up with the inconvenience of the reduced pressure in the city during the time the pumping-reservoir was being filled.[1] With a 13-inch branch, and with the city-supply entirely shut off, the daily requirements of the pumping-reservoir could be supplied as follows:—

1st. The tank being full;

Reduced level of waste-weir	1,037·0	feet.
„ „ of high-water level in reservoir	989·75	„
Head available	47·25	„
Length of pipe to Ambajheri	4,700	yards.
Diameter of pipe	13	inches.

the discharge is, according to Box,

$$D = \left(\frac{3\,d^5 \times H}{L}\right)^{\frac{1}{2}} = \left(\frac{39^5 \times 47\cdot25}{4{,}700}\right)^{\frac{1}{2}} = 950 \text{ gallons per minute.}$$

The requirements being 438,400 gallons in twelve hours, the supply could be given in 7·7 hours.

2nd. The tank being at its lowest estimated level, *i.e.*, 11·3 feet below weir crest, or 11 feet on the gauge;

Reduced level of weir	1,037·0	feet.
„ „ of low-water level	1,025·7	„
„ „ of high-water level of pumping-reservoir	989·7	„

The diameter and length being constant, the discharge varies as $\sqrt{H}$;

whence $\sqrt{47\cdot25} : 950 = \sqrt{36} : 820,$

therefore $D = 820$ gallons per minute;

and the daily demand could be supplied in 8·9 hours; *i.e.*, it would only require 1·2 hour more than when Ambajheri tank was quite full.

It was not, however, considered desirable to shut off the city entirely, and a series of experiments with the pressure-gauge were undertaken, to ascertain what effect the draught in the city had on the available head; but it was recognized that the results could only be approximately correct, because the draught in the city is a variable quantity, depending on the season of the year. It was not, however, possible to defer the preparation of the project until gaugings could be taken in May, the extreme hot-weather month. The gauge was fixed at the point of take-off, and the readings were first taken throughout the twenty-four hours. The water-level at Ambajheri stood at 1,031·5 feet, or 5·5 feet below the weir-crest. The reduced level of the pipe was 972·0 feet, so that the static head was 59·5 feet. At 5 A.M. the pressure-gauge stood at 22½ lbs. From 5 A.M. to 11 A.M. it descended to 17½ lbs.; from 12 noon to 5 P.M. it stood at 19¼ lbs.; from 5 P.M. to 7 P.M. at 20 lbs.; from 7 P.M. to 1 A.M. it rose to 24 lbs.; between 1 A.M. and 4 A.M. it stood at 24½ lbs.; and at 5 A.M. it had fallen to 22½ lbs.

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[1] Since the above was written, the municipality has decided to lay down a separate 12-inch main from Ambajheri, as it was found that the pressure in the city was inconveniently interfered with during the extreme hot-weather months.—E. P.

The maximum pressure recorded was between 12.30 P.M. and 4 A.M., when 25 lbs., or 57 feet head, were registered; so that practically there was no draught whatever in the city between those hours. The draught in the city commenced at 4.30 A.M., and by 7 A.M. the gauge had fallen to 18 lbs. The greatest draught took place between 7 A.M. and 10 A.M., between which hours the lowest pressure registered was 17¼ lbs., or 39·6 feet head. The draught, therefore, reduced the head 57 − 39·6 = 17·4 feet.

The draught continued up to 1 P.M., but in a much less degree, and by that time the pressure had risen from 17¼ lbs. to 19 lbs. From this hour to 5 P.M. the gauge stood almost steady at 19¼ lbs., showing that a small amount of draught continued in the city throughout the day. After 5 P.M. the draught became less and less; at 7 P.M. it had risen to 20 lbs.; and thence rose steadily to 24 lbs. at midnight. The experiments showed that the pumping-reservoir connecting-pipe should not be opened at all between 5 A.M. and 11 A.M.; it might be partially opened during the afternoon and evening; and fully opened from 11 P.M. to 5 A.M. It remained now to ascertain what the discharge through the connecting-pipe would be,

(i) With the city-pipe full open.

(ii) With the city-pipe full open and the connecting-pipe only partially so.

The theoretical discharge through the 13-inch connecting-pipe, with the city-pipe closed and the reservoir at Ambajheri quite full, has already been shown to be 950 gallons per minute. The actual discharge, with the water-level at 1,031·5 feet, or 5·5 feet below high-water level, was gauged to be 1,250 gallons per minute, showing a difference of 300 gallons per minute.

An experiment was now made with the city-pipe, as well as the connecting-pipe, full open. The pressure-gauge at 11 P.M. stood at 24 lbs., the water-level in the tank being 1,031·5 feet. On opening the connecting-pipe fully, the pressure dropped to 11 lbs., and the discharge was gauged to be 1,125 gallons per minute, or 10,800 cubic feet per hour. If this discharge continued from 11 P.M. to 4.30 A.M., the quantity delivered would be 10,800 × 5½ = 59,400 cubic feet, the full maximum requirement being 70,144 cubic feet. This leaves 10,744 cubic feet to be supplied during the day with the connecting-pipe partially closed. Further experiments showed that all the public standards in the low-pressure area of the city could be fully supplied when the pressure at the point of take-off was reduced to 16 lbs. The discharge was then gauged to be 1,560 cubic feet per hour; and, taking this minimum quantity for the calculations, though it is known that the pressure rises considerably in the afternoon, and rapidly after 5 P.M., the balance for the full maximum requirements could be supplied in $\frac{10,744}{1,560} = 7$ hours; *i.e.*, between 4 P.M. and 11 P.M.

BRANCH PIPE TO PUMPING-RESERVOIR.

The 13-inch branch pipe connects the city-main from Ambajheri with the pumping-reservoir; it is 735 feet long, and the valve which governs it is placed close to the take-off. The reduced level of the main at this point is 971·8 feet, and that of the branch-pipe where it joins the reservoir is 987·17 feet, showing a rise of 15·37 feet. The details of the pipe, which is plain spigot-and-socket throughout, are as follows:—

Length.	Diameter.	Length of each Pipe.	Depth of Socket.	Thickness of Metal.	Mean Weight.	Number of Pipes.	Total Weight.
Yards.	Inches.	Feet.	Inches.	Inch.	Cwts. qrs.		Tons.
245	13	9	4½	$\frac{9}{16}$	7 0	82	28·18

A chamber, in which is a pressure-gauge connected with the main, is constructed close to the take-off, exactly over the pipe. It is built of brick, circular in plan, with a domed roof. The interior diameter is 4 feet; the height to the springing is 8½ feet. The cost of this was Rs.230. The total cost of the 13-inch branch, with all specials and valves, including the gauge-chamber and fittings, was Rs.4,886, the rate per ton for the completed work being Rs.162·87.

THE PUMPING-RESERVOIR.

The pumping-reservoir into which the 13-inch connecting-pipe discharges (Fig. 3, Plate 1) measures 150 feet by 40 feet by 18 feet, the full water depth being 17 feet 3 inches. It has a total capacity of 103,500 cubic feet, and an available capacity of 95,000 cubic feet, or 1·35 times the maximum daily requirements, which are 70,144 cubic feet in twelve hours. The excavation was through 13 feet of black soil and yellow clay; at this depth soft gneiss and clay were met with, and, at an average of about 19 feet, soft rock of disintegrated gneiss. The level of this soft rock was irregular, but it did not vary more than 3 feet over the whole excavated area. Very little difficulty was experienced from accumulations of water, and the foundations were easily kept clear with a double-action hand-pump. The foundations were levelled up with concrete, the minimum thickness being 2 feet. Careful tests were made to arrive at the correct quantity of "matrix" to be used with the other materials; and it was ascertained that, with 75 cubic feet of 1¼-inch broken stone and 25 cubic feet of coarse gravel, 27·7 cubic feet of mortar were necessary to properly fill up the interstices.

It was also ascertained that the 9-inch layer of wet concrete of the above materials, on being thoroughly consolidated, was reduced to 7·65 inches; and that 100 cubic feet of consolidated concrete required the quantity of materials given above. The matrix was composed of two parts of sand and one part of lime, and the 27·7 cubic feet of mortar required one-third more dry materials, or 12·5 cubic feet of lime and 24·5 cubic feet of sand—a total of 37 cubic feet. The lime was burnt with coal from nodular kunkur, it was then slaked and screened and used fresh from the kiln. The mortar was ground by steam-power in a mill, the proportional parts being carefully measured before mixing. The stone for the concrete was broken into cubes and passed through a 1¼-inch ring; it was then screened and washed and stacked 9 inches deep in a box measuring 10 feet by 10 feet. Over this, 3 inches of well-washed gravel was evenly spread, and over that 3·6 inches of mortar was laid; these measurements accord with the proportions quoted above. The materials were then thoroughly incorporated by hand labour, and carried by head-loads in iron pans to the site of the work, where the mixture was carefully deposited and rammed in layers not exceeding 9 inches in thickness. The top 9-inch layer of the "floor" was treated differently. The broken stone was made up of screenings and cubes and passed through a 1-inch ring and the proportion of gravel was increased—each 100 cubic feet of concrete being made up of 50 cubic feet of screenings and broken stone, 50 cubic feet of coarse gravel, and 27·7 cubic feet of mortar. This was rammed until the mortar creamed up, when the consolidation was completed by beating the surface lightly with split bamboos and tight.

A flight of masonry steps, running parallel to the side walls at the south end, gives access to the interior of the reservoir. For cleaning purposes, the water can be pumped out within 1 foot of the floor-level by steam-power, and the remaining quantity can be easily dealt with by temporarily-erected hand-pumps. The walls were constructed of basalt rubble masonry with coursed faces, the mortar being made with the same proportions as for the concrete; they are 18 feet high, 8 feet thick at the bottom and 3 feet at the top, the inner face being vertical. Near the top of the walls stone corbels, 5 feet from centre to centre, were built on to support a gangway of planks running all round the reservoir. In the rubble masonry the greatest care was taken in the proper bedding of the stones, and in preserving an uneven surface, free from horizontal joints. The joints were not pointed and no plaster was applied, and so far as it could be ascertained the reservoir is absolutely water-tight.

Behind the walls, selected material was carefully consolidated and kept level with the masonry during construction; the influence of the pressure of this backing was taken into consideration in calculating the thickness of the walls. The average discharge through the connecting-pipe has already been shown to be 1,125 gallons per minute, or 10,800 cubic feet per hour; to completely fill the reservoir 9·5 hours are required with the main to the city full open.

The maximum daily requirements of 438,400 gallons can be supplied at night under the same conditions in 6·5 hours; and, when the scheme is working up to its maximum limit, the supply will be received in 5·5 hours at night with the city-main full open, and from 4 to 11 P.M. with the connecting-pipe partially open. An enamelled-iron gauge is fixed in the reservoir for indicating the depths whilst pumping or filling. On the top of the masonry walls which form the reservoir, and which are 1 foot 6 inches above ground level, brick pillars, 3 feet wide, 1 foot 10½ inches thick and 5 feet 3 inches high, are built 7 feet 6 inches apart, the spaces between being filled in with a 9-inch brick wall. The pillars carry 9-inch stone caps which support the ends of the iron trusses. The roofing consists of eighteen B. W. G. corrugated-iron sheets, with curved sheets on cast-iron brackets forming a ventilator at the top.

The open spaces at the ventilator and between the side walls and the roof are filled in with galvanized iron-wire netting of

2-inch mesh, to prevent the entrance of birds. The end walls are gabled and built of brick-work. The iron trusses are of the simplest possible form, the span is 43 feet from centre to centre, and they are spaced 10 feet apart. The purlins are 5 feet apart and are of angle-bar, each measuring 3½ inches by 2½ inches by ⅜-inch, placed back to back. The trusses were erected on a platform constructed of rails fished together, which was moved along as the work required on horizontal rails laid on the tops of the side walls; they were calculated to bear a load of 43 lbs. per square foot normal to the roof surface, of which 30 lbs. was wind-pressure. The rise of the roof is one-fourth of the span. Two doors have been provided in the east wall of the superstructure, one at the head of the steps leading to the interior, and one large one in the centre, for facilitating the fixing of temporary pumps when cleaning out the reservoir. The engine-room is situated at the north end of the reservoir, and is 26 feet 9 inches long by 41 feet broad, with an additional space measuring 19 feet 9 inches by 9 feet 6 inches on the west side in front of the boilers, in order to give adequate space for firing under cover (Fig. 4, Plate 1). This room has its floor-level 2 feet 3 inches below the top of the reservoir-walls and contains the steam-pumps and boilers in duplicate. The pumps are placed close to the end wall of the reservoir, and are 14 feet from centre to centre; the boilers are placed at right-angles to these, 7 feet 6 inches from centre to centre. The floor is of stone flagging, the walls are of brick-work, the minimum height to the bed-stone level being 7 feet 6 inches. The foundations for the boilers and pumps, shown in Fig. 5, are taken down to good firm soil and built up with concrete and brick-work; the bed-stones are in all cases of sandstone blocks 1 foot thick. The roof is of the same description, and in prolongation of that over the reservoir; the covering over the space in front of the boilers being in continuation of the side at a slightly flatter slope, so as to give a minimum headway of 6 feet at the entrance. There are two entrances into the reservoir leading on to the gangway, and ample ventilation is afforded by the doors and windows in the north and east walls. The windows are all covered with wove-wire netting.

In the engine-room a work-bench, 11 feet long, has been fitted up; two good reflector-lamps for night-work, and a clock, have also been provided. On the north wall, connected with the rising-main, is fixed a gauge to mark the pressure; from which any obstruction in the pipe whilst the pumps are working can be at once detected, and also any loss of water from the main when the pumps are at rest. The coal is stacked on a raised platform close to the engine-room; no shelter-shed is provided for this, as it is one of the peculiarities of Warora coal that exposure in no way causes it to deteriorate in quality. Within a few hundred feet north of the reservoir are situated the quarters for the staff of the engine-room, and the general store-room. This building is not altogether new; some old out-houses existed here, and were converted to the above purpose.

	Rupees.
The cost of the reservoir was	33,454
The cost of the roofing over it	8,051
Total	41,505
The cost of the engine-room and roof was	6,352
The cost of converting the old out-houses into staff-quarters and store-room was	1,866
Grand Total	49,723
The cost per 1,000 gallons of water stored was	64·1
The cost per square foot of plinth area for the engine-room was	4·24

STEAM-PUMPS.

The type selected was a double compound "Worthington" steam-pump. The engines are non-condensing, and were made by Messrs. H. R. Worthington, of New York, and supplied through the Worthington Pumping-Engine Co., of London. The high-pressure cylinder is 12 inches diameter, the low-pressure cylinder 18½ inches diameter; the double-acting water-plunger is 10¼ inches diameter, the stroke being 10 inches. The pump delivers 536 gallons per minute when running at a piston speed of 84 feet per minute, or fifty double strokes, against a head of 117 feet through 8,000 feet of 8-inch pipe, the steam-pressure in the boiler being 90 lbs.

The suction-pipe being a long one, 21¾ feet, a "foot-valve" is placed on it to keep the pipe and cylinders charged with water, so that the pump on starting has not to free itself and the suction-pipe of air. A "vacuum chamber" is also added on the top of the suction-pipe, in order, by expansion of the air, to give a uniform flow into the pump. A side pipe and strainer are attached to the suction-pipe, close to the pump, to prevent the admission of dirt. In the hand-hole plate of the side pipe a thumb-plug is provided, which, if removed when the pump is stopped, admits air into the suction-pipe, and prevents the water from siphoning out of the cylinders. A "check-valve" is placed on the delivery-pipe close to the pump, for use when the latter is opened and examined for repairs.

A "waste-delivery" pipe, 1½ inch in diameter, is attached to the pump, so that the pump on starting can free itself of air whilst the pressure is kept off it by the check-valve. A charging-pipe, 1 inch diameter, connects the delivery-pipe beyond the check-valve with the suction chamber; and is provided for the purpose of filling the cylinders and suction-pipe before starting, in case they have been purposely emptied. The pumps are in duplicate, one being shut off by a sluice-valve from the other whilst it is working, and each delivering into an 8-inch rising-main running between them. The suction-, vacuum- and straining-pipes are all 8 inches in diameter; the delivery-pipe, from the pump to its junction with the rising-main, is 7 inches in diameter.

BOILERS.

The boilers to supply steam to the pumps above described are in duplicate, and are of the locomotive multitubular type, manufactured by Messrs. Marshall and Sons of Gainsborough. Each boiler is of 30 HP., with steel shell and Bowling-iron fire-box; the extreme dimensions are 16 feet 5 inches in length and 4 feet 4 inches in diameter. The weight of each boiler is approximately 8½ tons. Each boiler has sixty-eight 2½-inch tubes, and is made to stand a working-pressure of 90 lbs. per square inch. A Worthington donkey-pump, size 3 inches by 2 inches by 3 inches, supplies feed-water to either boiler. A "heater" is attached, through which all the feed-water is pumped, and into which all the exhaust-steam is led. All steam-connections and pipes are coated with 1 inch of non-conducting "fossil-meal" composition. The boilers are placed at right-angles to the axis of the pumps, and 7 feet 6 inches apart from centre to centre.

A 3½-inch pipe conducts the steam to the first pump, placed 6 feet 3 inches from the end of No. 2 boiler; and a 2½-inch steam-pipe leads on to the second pump, placed 14 feet from the first. The exhaust steam is led from No. 2 pump by a 3½-inch pipe, enlarging to 5 inches beyond No. 1 pump, into the "heater."

The cost of the pumps and boilers was as follows:—

Cost of each steam-pump with spare articles and fittings delivered at Nágpúr	5,265
Cost of each 30-HP. boiler with feed-pump, connection-pipes and fittings at Nágpúr	7,454
Total	12,719
Cost of duplicates of above	12,719
Total	25,438
Cost of erecting and fitting, including all engine-room fittings and requisites	3,653
Grand Total	29,091

RISING-MAIN.

The reduced level of the centre of the pump-plunger is 990·38 feet, that of the inlet-pipe at the service-reservoir is 1,093·7 feet, and that of the top-water 1,107·5 feet; hence the total height the water has to be forced is 117·1 feet.

The rising-main (Fig. 3, Plate 1) is 8 inches in diameter, and 8,000 feet long; and a maximum delivery of 600 gallons per minute, or 1·6 cubic foot per second, can be obtained through this. The area of the 8-inch pipe is 0·343 square foot, and the velocity in the pipe to deliver the above quantity must be 276 feet per minute. As the velocity should in no case exceed 400 feet per minute, it is well within the limit.

The frictional resistance in the pipe, calculated by Fanning's formula $\left(h \text{ inches} = \frac{4\,l\,m\,v^2}{29\,d}\right)$, is 92 feet.

The statical head on the pipe near the pump is 117 feet; the motive pressure is 92 feet; the total pressure being 209 feet, or 90 lbs. per square inch.

The pipes are $\frac{15}{32}$ inch thick, and were tested before delivery to 300 feet head; they are all plain spigot-and-socket with lead joints, and were obtained from Messrs. A. J. Stewart, of Glasgow, through Messrs. Richardson and Cruddas, of Bombay. Wide joints were adopted because much of the ground was very uneven, and in parts of a rocky character, and a certain amount of flexibility without producing leakage was a desideratum. The pipes were cast in green sand, *i.e.*, without the moulds being dried in a stove, and at an angle of 45°. They are cheaper than vertically-cast pipes in dry sand; and, for the small amount of pressure on them, are practically just as good. They are coated inside with coal-pitch and oil according to Dr. Angus Smith's process.

The particulars of the pipes laid are given in the following Table:—

Diameter.	Length.	Depth of Socket.	Thickness.	Mean Weight.	Number of Pipes.	Total Weight.
Inches.	Feet.	Inches.	Inches.	Cwts. qrs.		Tons. cwts.
8	9	4	$\frac{15}{32}$	3 2	889	150 16

There are two 5-inch scour-valves and eleven air-valves on the line; a "reflux" valve is placed just outside the service-reservoir, and another close to each of the pumps. A 3-inch ball-hydrant is placed close to the engine-room, so that a hose may be attached to a stand-post for washing out the boilers. All fittings and valves are of the Glenfield Co.'s make. The cost of the plain 8-inch pipes delivered at Nágpúr was Rs.6 6a. per cwt. The jointing cost Rs.15 per ton, the trenching being a separate item. The whole cost, including fittings, was Rs. 29,765, or Rs. 197·3 per ton.

SERVICE-RESERVOIR.

The service-reservoir, Figs. 6 and 7, Plate 1, is divided into two compartments, each measuring 75 feet by 40 feet by 16 feet. The available capacity is 82,500 cubic feet, the total capacity being 96,000 cubic feet. The available capacity is 1·2 the estimated maximum daily requirement. The reservoir is situated on the side of a hill commanding the whole of the high-level area; the top-water is 70·5 feet above the weir-level at Ambajheri. The foundations are on hard basalt rock; they were very uneven and were levelled up with concrete in the same manner as described in detail for the pumping-reservoir.

The walls are of rubble masonry with coursed face-work; in order to minimise the chance of leakage, a core of rubble masonry 3 feet wide was built in the centre of the concrete under the walls down to the solid rock. The centre wall is built 9 inches lower than the side walls, and the overflow channel is on the top of this, the water being carried away by a 6-inch down-pipe. The top of the reservoir was finished in exactly the same manner as that of the pumping-reservoir, with corbel-stones and a planked gangway all round the interior. The floor-surface was treated in the way already described, neither lime-plaster nor cement being used; no special pointing was done to the joints of the walls. The reservoir, on being filled, proved perfectly water-tight. The walls are all 3 feet thick at the top; but the front wall, which has no earth backing, is broader at the base than the others, the necessary thickness being calculated in each case. The centre wall has a batter on both sides; it is 4¼ feet thick at the top and 9⅓ feet at the base. Access to each compartment is afforded by a flight of masonry steps running parallel to the side of the centre wall. The superstructure and roofing are in every respect identical with those of the pumping-reservoir, the span being the same. The inlet-pipes are 8 inches in diameter; the rising-main is carried through the wall, 2 feet above the floor-level, at its junction with the centre partition, and branches off into each compartment. Each inlet has a bell-mouthed opening, and is governed by a sluice-valve inside the reservoir, worked by a rod-and-pillar screw from a platform at the top. In each compartment is an enamelled-iron gauge for reading the water-levels.

The outlet-pipes are 10 inches in diameter, and are carried under the front walls and unite outside the reservoir. The pipe from each compartment is governed by a sluice-valve; both of these, as well as the "reflux" valve on the rising-main, being in a covered well at the foot of the front wall; the valves are worked by a spindle from the top. Details of the inlet and outlet are shown in Fig. 8. A 6-inch scouring-pipe is placed at the centre of each compartment, the floor sloping towards it from all sides. The valves for these are outside the reservoir in covered wells. The special pipes in connection with the reservoir have all flanged joints with turned faces, and are jointed with lead washers. The details of the pipes are as follows: The outlet-pipes have bell-mouthed caps which are covered with wove-wire netting of 3 meshes to the inch.

The dimensions of the special pipes are as follows:—

Inside Diameter.	Thickness of Metal.	Diameter of Flange.	Pitch of Bolt-holes.	Thickness of Flange.	Number of Bolt-holes.	Diameter of Bolts.
Inches.	Inch.	Inches.	Inches.	Inch.		Inch.
10	$\frac{9}{16}$	16	13¾	$1\frac{1}{16}$	8	¾
8	½	13⅜	11½	1	6	¾
6	½	11	9¼	⅞	6	⅝

The specials were delivered at Nágpúr for Rs.8 9a. per cwt.

A small house has been constructed close to the reservoir, consisting of one room measuring 12 feet by 12 feet, and a verandah 12 feet by 5 feet; this is for the Chowkidar and for the safe custody of the valve-keys, &c.

The reservoir, including all special pipes and valves, cost Rs.31,152; the superstructure and roofing Rs.10,791; the Chowkidar's house Rs.617. The total cost per 1,000 gallons storage was Rs.70. The area of reservoir roofed over was 7,352 square feet; the rate per square foot for roofing being R.1·13.

DISTRIBUTION SYSTEM.

The supply was fixed at the rate of 30 gallons per head per day for the European population (including the allowance for horses and cattle, and 8 gallons per head for natives), to which was added the maximum daily requirement for the Bengal Nágpúr Railway, making a total of 438,400 gallons per day.

The pipes were calculated to supply this quantity in twelve hours, and vary from 10 inches to 3 inches in diameter. It would, of course, have been advisable to have arranged for them to be able to supply the quantity in the six hours during which the maximum draught takes place; but financial considerations prevented this from being done, as the sizes of the pipes and the cost of the distribution system would thereby have been greatly increased; the limited amount that the municipality could afford being 3 lacs of rupees. The pipes were all cast in green sand; the joints throughout are plain spigot-and-socket, and run with lead. The pipes were obtained, through Messrs. Richardson and Cruddas, of Bombay, from Messrs. Stewart and Co., of Glasgow, and were certified at the time of delivery to have been tested up to 300 feet head. The least effective head in the civil station is on the "Ridge," where it averages 13 feet, but elsewhere it averages 35 feet. The average effective head in the city is 24 feet. The total length of pipes laid in the high-level extension is 13 miles, and the weight is 632 tons. The maximum pressure is 134 feet, or 58 lbs. per square inch. The total weight of pipes laid in the civil station is 419 tons, and in the city is 213 tons; total, 632 tons.

The pipe-lines are, as far as possible, divided into complete circuits, with sluice-valves at each junction, and scour-valves wherever suitable places occur. Ball-hydrants are placed at intervals along the lines, for purposes of fire-service, road-watering and the discharge of air; the stand-posts for these fit

2½-inch hose connections. Throughout all the native bazaars and the city, public drinking-fountains have been erected; these are of the self-closing type known as "Kennedy's Patent," in which the valve is opened by raising a weight attached to a horizontal spindle. A masonry platform and proper drainage-channels are provided round each standard. There are at present seventy-seven of these drinking-fountains erected over the high-level area; sixty of them are in the city and seventeen in the civil-station bazaars. The houses of the European inhabitants, and those of the well-to-do natives, will be connected to the mains by service-pipes; these pipes will be, as they are at present all over the low-pressure area, of galvanized iron. Water is supplied to the railway company, the gaol, and other institutions, at the rate of 3,000 gallons per rupee. For private European houses, an average daily allowance of 450 gallons is provided at the same rate; any quantity used in excess of this entails an extra charge. All the valves and fittings are of the Glenfield Co.'s make.

The total cost of the distribution system was Rs.125,056, and the population supplied 44,000, the cost per head being Rs.2·84.

STEAM-PUMP TRIALS.

For the purpose of investigating the capabilities of the compound steam-pumps supplied by the Worthington Pumping-Engine Co., the steam-cylinders were fitted with indicators, from which diagrams were obtained for the calculation of the indicated horse-power.

The investigation included the determination of the following points:—

(i) The indicated horse-power.

(ii) The pump horse-power.

(iii) The mechanical efficiency, or ratio of the pump horse-power to the indicated horse-power.

(iv) The velocity of the water in the 8-inch rising-main.

(v) The "duty," or ratio of the product (in foot-pounds) of the weight of water lifted into the height, to 112 lbs. of coal burnt.

(vi) The amount of "slip" in the pump.

(vii) The coal-consumption per horse-power.

The steam-pressure in the boiler was kept at 90 lbs. during the trial, and the pump run at a regular speed of 50 double strokes per minute. Owing possibly to the joints in the suction-pipe and elsewhere not being absolutely tight, the full 10-inch stroke could not at the time be obtained, the average length being $9\frac{11}{16}$ inches. The pump-discharge was 536 gallons per minute; and, the full estimated requirements being 438,400 gallons per day, the supply can be given with fourteen hours' pumping. With the pumps delivering 536 gallons per minute, the velocity in the 8-inch rising-main was 245 feet per minute. At this speed, the pressure-gauge in the engine-room, attached to the rising-main, showed 85 lbs. Of this, 50 lbs. is due to the static head of 115 feet, and 35 lbs. is due to frictional head. The total pressure is equivalent to a head of 197 feet, and the pressure increases rapidly if any attempt is made to drive the pumps faster. The indicated horse-power calculated from the mean pressures in the high- and low-pressure cylinders, as given by diagram, is 36·2. The pump horse-power calculated from the work actually done, is 31·6. The mechanical efficiency, derived from these, is 87 per cent. The duty is not quite 16,000,000 foot-lbs. In estimating the duty of water-works engines, the steam-consumption is usually alone dealt with, and an evaporation of 10 lbs. of water per 1 lb. of coal assumed. In practice, however, average English coal has an evaporative effect of not much more than 8 lbs. The evaporative power of the Warora coal used is scarcely 60 per cent. of that of English coal. Had the latter been used, the duty would have been approximately 26,000,000 foot-lbs. The consumption of coal per indicated horse-power is 12·2 lbs., which, reduced to the English equivalent, is 7·3 lbs. This is high if compared with the best English practice; but it is possible that the form of the grate and fire-bars are not well adapted to the peculiarities of Warora coal. The results of the trials were not as good as had been anticipated.

The Paper is accompanied by twenty-two drawings, from which Plate 1 has been prepared.

[APPENDIX.

APPENDIX.

TABLE I.—AREA AND CAPACITY OF RESERVOIR FOR EACH FOOT IN HEIGHT ABOVE EXTREME LOW-WATER LEVEL.

Height of Water above extreme Low-water Level.	Water Area in Square Feet.	Capacity in Cubic Feet.	Reduced Level.	Remarks.
22·3	16,319,400	253,000,000	1,037·00	Level of waste weir.
22·0	16,206,000	249,000,000		
21·30	15,950,000	238,500,000		
21·0	15,828,000	233,881,500		
20·0	15,450,000	218,242,500		
19·0	15,072,000	202,981,500		
18·0	14,694,000	188,098,500		
17·0	14,316,000	173,593,500		
16·0	13,938,000	159,466,500		
15·0	13,560,000	145,717,500		
14·0	13,190,340	132,342,330		
13·0	12,820,680	119,336,820		
12·0	12,451,020	106,700,970	1,026·20	
11·5	..	100,500,000		
11·0	12,081,360	94,434,780		
10·0	11,711,700	81,538,250		
9·0	11,024,500	71,170,150		
8·0	10,337,300	60,489,250		
7·0	9,650,100	50,495,550		
6·0	8,962,900	41,189,050		
5·0	8,275,700	32,569,750		
4·0	7,571,000	24,646,400		
3·0	6,866,300	17,427,750		
2·0	6,161,600	10,913,800		
1·0	5,456,900	5,104,550		
0·0	4,752,200	..	1,014·70	

TABLE II.—DAILY CONSUMPTION, FROM ALL CAUSES, OF WATER FROM AMBAJHERI RESERVOIR.

1	2	3	4	5	6	7	8
—	Year.	Total Annual Consumption in Cubic Feet.	Average of Five Years.	Days Interval between High-water Level and Low-water Level.	Average of Five Years.	Daily Consumption in Cubic Feet.	Average Daily Consumption of Five Years in Cubic Feet.
1	1872-73	112,098,500	..	263	..	426,230	
2	1873-74	108,300,300	..	248	..	436,693	
3	1874-75	115,700,000	..	264	..	438,257	
4	1875-76	116,000,000	..	285	..	417,543	
5	1876-77	101,500,000	*110,719,760*	281	*268*	361,209	*415,987*
6	1877-78	103,300,000	..	244	..	423,360	
7	1878-79	95,700,000	..	231	..	414,285	
8	1879-80	109,700,000	..	252	..	435,317	
9	1880-81	101,500,000	..	243	..	417,695	
10	1881-82	109,700,000	*103,980,000*	263	*246*	417,110	*421,553*
11	1882-83	112,600,000	..	267	..	421,722	
12	1883-84	104,000,000	..	245	..	424,489	
13	1884-85	99,400,000	..	247	..	402,429	
14	1885-86	116,700,000	..	295	..	395,593	
15	1886-87	108,759,000	*108,291,800*	221	*255*	492,122	*427,271*
Average .		..	..	..	*256*	..	..

TABLE III.—STATEMENT SHOWING PERCENTAGE OF RAINFALL IMPOUNDED IN THE RESERVOIR.

1	2	3	4	5	6	7	8	9
—	Years.	Total Rainfall (Monsoon).	Rainfall which Filled the Tank.	Rise of Water-Level in Feet.	Number of Days over which Rain on Column 4 Spread.	Percentage of Rainfall impounded from Drainage-Area alone.	—	Rainfall.
1	1873	24·26	24·26	6·0	90	15		
2	1874	41·22	23·34	8·5	54	27		
3	1875	51·31	19·80	8·0	25	30		
4	1876	37·76	26·24	8·25	47	21	*21·0*	*23·5*
5	1877	42·32	23·09	6·9	41	20		
6	1878	54·57	21·19	7·0	36	22		
7	1879	46·76	21·49	6·5	58	21	*19·6*	*25·3*
8	1880	38·45	34·39	7·0	88	13		
9	1881	55·18	20·05	6·9	26	25		
10	1882	41·97	20·37	7·5	13	27		
11	1883	58·99	19·11	7·7	20	30		
12	1884	49·41	18·34	7·1	12	31		
13	1885	32·03	22·48	6·8	38	20		
14	1886	38·67	22·18	8·1	32	26		
15	1887	54·24	19·79	7·1	30	27		
16	1888	31·88	30·38	6·9	85	14	*20·0*	*27·9*
17	1889	34·84	29·07	9·1	79	21		
18	1890	46·90	24·37	8·4	59	25		
Average .		39·8 for 30 years	23·33	..	46	23	*20·3*	*25·6*

(Paper No. 2617.)

The Waste of Water in Public Supplies, and its Prevention."

By William Hope, Assoc. Inst. C.E.

INTRODUCTION.

The fact that a large portion of the whole quantity of water in most public supplies is wasted, or lost, without the knowledge of the Water Authorities or the consumers, is as incontrovertible as it appears to be difficult to conceive. An idea of the real condition of things may be gained by regarding the system of mains, pipes, and fittings, supplying any given community, as a rapidly-leaking reservoir, and by considering that the water which actually reaches the consumers is merely the overflow from that reservoir, or, in other words, the volume supplied to that reservoir in excess of the leakage.

Even now, the majority of the water-undertakings of this country lose by leakage more than one-half the total quantity of water supplied from the source. The proportion is often higher, and rises in many cases to three-fourths, or more; while, in comparatively new countries, such as America, Australia, and New Zealand, the portion so lost is on the average still greater.

A growing, but still imperfect knowledge of these facts has brought about the more obvious remedies; and these, combined with the extension to more than six-and-a-half millions of persons of the method of waste-prevention introduced by Mr. G. F. Deacon, M. Inst. C.E., and described by him in the Proceedings,[1] has lately further improved the average, and, in particular instances, has caused the total rate of supply of water from the source to fall so low, by the reduction of leakage, without any restriction whatever of the quantity used, that a comparison between the present and past conditions at once confirms the accuracy of the statements made above.

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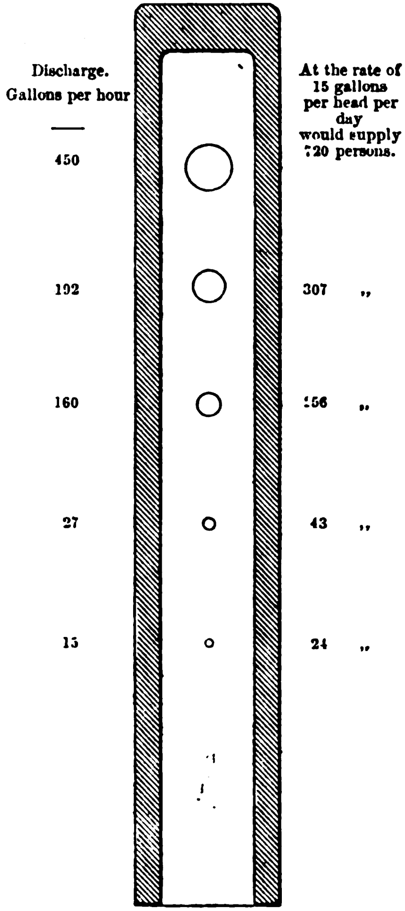
[1] Minutes of Proceedings Inst. C.E., vol. xlii. p. 143 *et seq.*

How easy it is to double or treble the demand upon the source of supply by permitting leakage in the water-mains, ferrules, pipes, and fittings may be readily understood from a consideration of the great waste of water occasioned by leaks of apparently insignificant size.

Fig. 1.


Discharge.
Gallons per hour
450
192
160
27
15
At the rate of 15 gallons per head per day would supply 720 persons.
307 „
256 „
43 „
24 „

Results of Experiments on the Flow of Water through Circular Holes in a half-inch lead-pipe, under a Pressure of 45 lbs. per Square Inch—Giving an idea of the Number of Persons that might be Supplied by the Discharge through Flaws of Various Sizes.

To illustrate this important point, *Fig. 1* shows a lead pipe drilled with various sized holes, the burr on the inside not being removed. The actual number of gallons per hour which passed through each hole under a pressure of 45 lbs. per square inch is noted on the drawing, together with the corresponding number of persons which that quantity would supply at the exceptionally high rate of 15 gallons per head per day. Leaks of magnitude varying from the fine needle upwards are almost innumerable in distributing-pipes and fittings. They arise from cracks and holes in the barrels and joints of cast-iron pipes, defects in the ferrules connecting the mains with the service-pipes, splits or other holes in the service-pipes, and defects in the fittings by which the water is drawn off. When underground, they are generally incapable of being detected by ordinary means. Even in comparatively retentive soil, their individual magnitude is often too small to cause superficial dampness or to waste away the surrounding ground into sewers and drains; and in such cases they do not make themselves known by the falling in of the surface. Of larger-sized underground leaks discharging through self-made channels into sewers and drains, previously unknown examples are now frequently discovered by the waste-water-meter system. They have been detected of almost every size, even up to continuously-flowing quantities sufficient for the supply of 2,000 or 3,000 houses.

Approximate Determination of Total Waste.

Before proceeding further with the details of the subject, it is clearly important to notice that supply and consumption are not equivalent or convertible terms.

The supply is the whole quantity of water drawn from a source. The consumption is the quantity of water which reaches the premises of the consumer and is drawn off for use, whether lavishly or otherwise. The waste, or loss, is the difference between these two, *i.e.*, the supply minus the consumption.

The water thus lost is a quantity entirely unknown to the consumer, and generally unknown also to the Water Authority, by whom much of it, often the whole, is, unfortunately, believed to be included in the consumption. There is no water-supply in which some unnecessary waste does not exist, and there are few supplies, if any, in which the saving of a substantial proportion of that waste would not bring pecuniary advantage to the Water Authority; whose object, therefore, should be to reduce the entirely harmful loss, and thus prevent the volume of water supplied from unduly exceeding the volume consumed. It is to be particularly noted that the "consumption" here referred to includes all lavish expenditure of water, all waste in the mode of use, all application or misapplication, the curtailment of which could possibly be regarded by the consumer as an interference with his privileges of free and unrestricted use of the supply. The "water wasted or lost," on the other hand, is a portion of the supply which cannot directly or indirectly benefit the consumer, and the saving of which must of necessity benefit everybody concerned.

The proportion between the supply and consumption may generally be ascertained, at least approximately, without much trouble or expense. In the majority of towns there is no consumption of importance between 3 and 4 A.M.; and if, for any manufacturing purpose, such consumption does take place, its amount can be readily ascertained. Most of the cisterns fill up before that time, and the morning use of water has not begun. Gaugings of the supply from the service-reservoirs, made every quarter-hour from midnight to 5 A.M., will give a result which in many cases must astonish the Water Authorities. For the purpose of such gauging, the supply to the service-reservoir must, of course, be entirely cut off. If the reservoir is of large area and the outflow relatively small, so that the fall of water-level is very slow, it is desirable to observe the varying levels by means of the hook-gauge; otherwise an ordinary levelling-staff, or fixed vertical gauge-board, is sufficient.

The minimum outflow will be found some time between midnight and 5 A.M., and if, about that period, closer readings are taken, the rate of flow will be found to be very nearly constant for an hour or two. This minimum flow is approximately the rate of useless and possibly harmful leakage of the district supplied; and, if the volume during one hour of such minimum flow be mutiplied by twenty-four, the result will be, approximately, the total daily waste of the district, and will, as already stated, be commonly found to be a large proportion of the whole quantity supplied. If Water Authorities would more frequently make this simple experiment, a better understanding of the importance of the subject would soon be arrived at. It is the first step towards producing that conviction as to the facts, without which no efficient reduction of the existing loss is likely to be undertaken. When this conviction has been reached, all doubt as to the expedience of taking remedial measures will be removed.

Outline of the History of Waste Prevention.

About forty years ago, when the pressures at which water was supplied began to be increased, it was recognized by those who paid attention to the subject that the pipes and fittings of a waterworks system could not be left to take care of themselves without suffering ever-increasing deterioration, even if the visible and more inconvenient leakages were from time to time cured. Naturally, the first repairs were those of visible defects in the house-fittings. Owing, however, to the originally inefficient construction of such fittings, the result of their repair soon proved to be unsatisfactory; and, in certain places in which the need was most pressing, the authority of Parliament was sought and obtained by the Water Authorities to interdict the use of existing domestic fittings, and to prescribe in detail the nature of all new fittings to be provided and fixed by the persons responsible for payment of the water rates.

At great cost to the owners and tenants, these powers were in a few cases enforced, and a considerable reduction of the supply, without any restriction of the consumption, was effected. By the decrease of velocity and friction thus brought about in the mains and pipes, the pressure was increased, and the mains and pipes thereupon leaked to such an extent that in some cases their entire renewal became necessary. The whole change was a much more serious one than had originally been contemplated. There can be no doubt, however, that, in those places in which it was thoroughly carried out, great advantages in point of economy and simplicity have since been reaped. Closely connected with such innovations, in this country at least, was the change in certain towns from intermittent to constant supply. While excessive waste continued, a constant supply could not be afforded; but, when excessive waste was prevented, constant supply became—as regards both the expenditure of water and of money—cheaper than intermittent supply. With these changes, became also apparent the necessity for a system of house-to-house inspection, by means of which the fittings could be brought under the observation of the Water Authority, and caused to be repaired or renewed.

The principal defects of this system of more or less complete renewal of the fittings and pipes, followed by house-to-house inspection for the maintenance of the fittings, were:—1. The great cost thrown upon the landlords or tenants by the renewal of pipes or fittings, which, though of indifferent quality, may not have been causing waste. 2. The great cost thrown upon the Water Authority by the renewal of pipes, which, though leaking in some places, may have been generally sound. 3. The frequent inquisitorial visits of the inspectors to private dwelling-houses, whether defects existed or not. 4. The impossibility of detecting certain hidden causes of waste, which are the most important of all. 5. The impossibility of checking the inspector's work, and of ascertaining how he spent his time.

The first successful attempt to remove the whole of these defects, and to substitute for a laborious, expensive, and comparatively inefficient method, a system of almost automatic inspection and localization of leakage, was initiated in connection with the Liverpool water-supply by Mr. Deacon in 1873. The developments of this method, and the improvements since introduced into it, have been so remarkable as to call for a further statement concerning it.

The Differentiating, or Waste-Water-Meter in its Present Improved Form.

In the case of the waste-water-meter, as in that of every important invention, experience has suggested alterations, which, without changing the principle, have simplified the apparatus or increased its efficiency.

The principle of the meter is simple enough. It consists substantially of a hollow truncated cone, the smaller end of which a disk tends, in virtue of a weight or spring, to fill. When a flow of water takes place through the cone from the smaller towards the larger end, the disk, being guided axially, necessarily moves in the same direction, and ceases to move the instant it reaches such a position that the pressure upon it, due to the velocity of the water between it and the side of the cone, is exactly equal to the counter-pressure of the weight or spring. The volume per hour being ascertained by actual test for each position of the disk, a pencil indirectly attached to the disk is caused to show upon the revolving diagram of the meter (*Fig. 2*) the actual rate of flow in gallons per hour, at every instant. Thus the flow is differentiated, its mode as well as its volume is automatically recorded, and the great advantages of a knowledge of the mode of flow are secured.

In order that every waste-water-meter of the same class may give identical results, it is necessary that not only the cone and disk and pressure of the weight or spring should be identical, but that the distribution of velocity over the transverse sectional area of the stream approaching the cone and disk should be uniform, and uninfluenced by the direction or section of the pipe through which the water reaches the meter. The unsteadiness and singing of a gas-jet, which may be produced by the partial closing of a gas-tap perhaps fifty or a hundred diameters distant from the jet, is a familiar phenomenon. In precisely the same way, the existence of valves, bends, or enlargements in the approach-pipes to waste-water-meters would, in the absence of proper precautions, cause important differences in their records.

In the earlier meters this difficulty was to a sufficient extent met, as illustrated in Mr. Deacon's Paper read before the Institution,[1] by causing the water to flow through equalising grids of precisely similar figures; but every one experienced in the management of waterworks knows the objections to grids or strainers on the direct line of any water main. Such meters were therefore placed on by-passes, so that when they were not in use the supply might be continued without passing through the grid; but this arrangement was expensive in first cost and increased the difficulty of management. By a simple device, Mr. Deacon subsequently removed the necessity for by-passes—so arranging the parts of the meter as to equalise the flow without any obstruction or risk of arresting foreign matter. He caused the flow towards the disk to take place over a turned circular edge, at which previously produced eddies, or irregular distribution of the flow, gave place to the greater influence of the law of uniform flow over a sharp edge. Such circular edges could be precisely reproduced, and were perfectly effective for the purpose intended. Moreover, when an abnormal flow takes place, as in the case of a fire, the disk of the meter now moves into such a position as to give the full waterway. A pair of longitudinal diaphragms check the helical motion which sometimes occurs. Since these changes were introduced, waste-water-meters have been placed direct upon the mains without any restriction of the flow, the whole resistance to the passage of water through the meter being no greater than that of a few yards of the main upon which it is placed. But perhaps the greatest improvement effected has been the inversion of the meter and the concentration in the disk of the counterbalance weight, formerly hung at the end of the wire by which the recording pencil was worked.

The meter in its present form is illustrated in *Fig. 2.*

The water entering at A passes around the outside, and beneath the horizontal circular edge B of the hollow cylinder C B. In this cylinder it flows upwards with a distribution dependent upon the law of constant flow over the sharp edge of the cylinder, so that irregularities in the distribution of the velocity produced at sections more distant from the cone are reduced to a minimum. The plane surface B B C C is one of the longitudinal diaphragms

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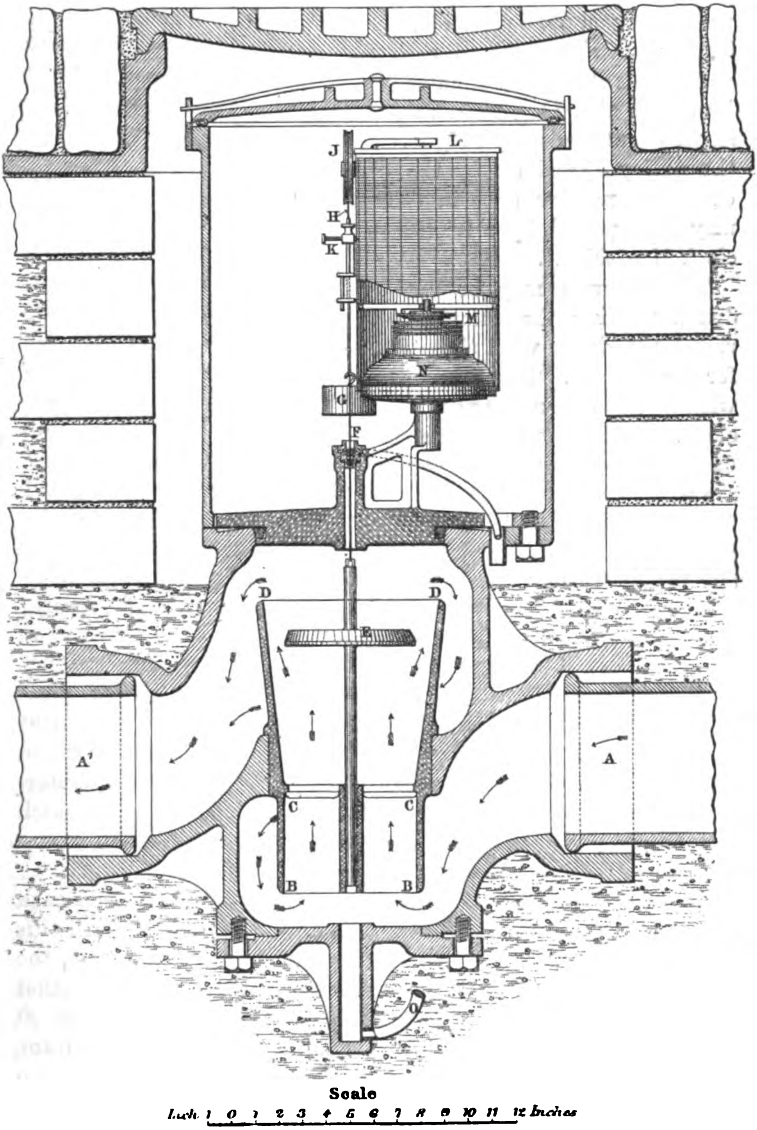
[1] Minutes of Proceedings Inst. C.E., vol. xlii. Fig. 11, Plate 6.

Fig. 2.


J
L
H
K
M
N
G
F
D
D
E
A'
A
C
C
B
B
O
Scale
Inch 1 0 1 2 3 4 5 6 7 8 9 10 11 12 Inches

Deacon's Waste-Water Meter.

by which the tendency to helical motion or vortex motion is checked. From the cylinder the water passes up the cone C D and lifts the loaded and guided disk E into such a position that the pressure upon its under side, due to the velocity of the water past it, is precisely equal to the effective downward weight. The water finds its exit, as it entered, over a sharp edge D, and continues its course along the main at A'. The wire F is kept taut by the small counterbalance weight G (hanging from the band H over the pulley J) and carries the pencil or pen at K. L is the drum, caused to revolve once in twenty-four hours or in six hours, as may be required, by a friction clutch M driven by the eight-day clock N within it.

The diagram may be rapidly mounted by withdrawing the drum, wetting the gummed edges of the paper, and folding it round the drum with the zero-line at a mark made on the drum for the purpose. It can be as rapidly removed, by simply cutting with a knife down the noon line. Except in connection with the clock, and between the fine wire, which may be removed at the cost of a few pence, and the gland through which it passes, there are no frictional bearing-surfaces whatever; and, as all parts except the body are made of non-oxidisable metal, it is not surprising that the cost of maintenance is trifling—much less than it can be in any integrating meter. The meter is placed under the carriage-way direct upon the main, and access to it is easily obtained through a strong surface box.

MAINTENANCE OF REDUCED WASTE.

It has been sometimes urged, in disparagement of the waste-water-meter system, that a district having once been got into proper order, very soon gets wrong again. Of course it does so if left to itself. Leaks constantly break out, but rarely or never cure themselves, and the broad problem to be solved is, by what means can they be most cheaply and quickly detected, localized, and repaired?

In the following Table, the condition of one hundred waste-water-meter districts in a single town on the first application of the system is given, and the condition of the same districts at different periods afterwards. In connection with these figures the Author desires to draw particular attention to the following facts. Before the introduction of the meters, the house-to-house system of inspection had been applied, with 3·9 inspectors to each 100,000 persons, and the result is shown by the first column of percentages of districts wasting different quantities of water. The waste-water-meter system was then put into operation with the same number of inspectors, and a remarkable change in a few months is indicated by the second column, where the majority of the districts are shown to be wasting the smaller quantities of water. Seven years later,

When Waste-Water-Meters were first applied it was found that the number of these	—	Some Months Later.	Seven Years later than the last Column.	Thirteen years later.
	Per cent.	Per cent.	Per cent.	Per cent.
Districts wasting less than 5 gallons per head per day was	0	2	20	40
Districts wasting between 5 and 10 gallons per head per day was	4	38	56	46
Districts wasting between 10 and 15 gallons per head per day was	4	40	24	14
Districts wasting between 15 and 20 gallons per head per day was	24	12	0	0
Districts wasting between 20 and 25 gallons per head per day was	24	4	0	0
Districts wasting between 25 and 30 gallons per head per day was	14	2	0	0
Districts wasting between 30 and 35 gallons per head per day was	14	0	0	0
Districts wasting between 35 and 40 gallons per head per day was	8	0	0	0
Districts wasting between 40 and 45 gallons per head per day was	2	2	0	0
Districts wasting between 45 and 50 gallons per head per day was	4	0	0	0
Districts wasting between 50 and 100 gallons per head per day was	0	0	0	0
Districts wasting between 100 and 150 (actual 132) gallons per head per day was	2	0	0	0
	100	100	100	100

the proportion of inspectors was less, and the percentages of the wasteful districts was, as shown by the third column, still lower. Thirteen years later, the number of inspectors per 100,000 persons was only 3·1; and the fourth column shows that all the districts occupy one of the three lowest classes of waste, which only 8 per cent. of them occupied at first; while 40 per cent. occupy the lowest class of all, in which at the end of the house-to-house system there were none. Thus it is clear that as the districts improve with the repairs and renewals, the facility with which they are further improved increases. The staff, in short, which is competent to bring the waste within moderate limits, is far more than sufficient to keep it down, or even to bring it within still lower limits.

PARTICULAR EXAMPLES OF THE APPLICATION AND MAINTENANCE OF THE WASTE-WATER-METER SYSTEM.

Out of the six-and-a-half millions of persons to whom the system has been applied, the Author has received from the engineers or managers of a few waterworks the particulars of their districts, and these have been tabulated in the Appendix, together with an estimate of the financial benefits resulting from the saving of water effected.

DOMESTIC FITTINGS.

It has often been urged that good fittings and pipes are the true means of preventing waste; but a full and frank admission of this does not render less obvious the advantages of any method by which the hidden waste—occurring even in entirely new districts—may be readily detected.

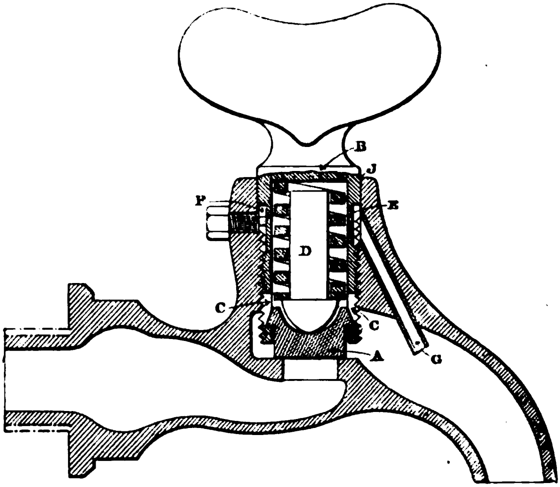
In districts where no pipe or fitting is more than a few years old, where every fitting before being fixed had been taken to pieces by the proper officer of the Water Authority, tested under hydraulic pressure, and, if found satisfactory, stamped, and where the pipes have been laid under the strictest conditions,—continuous waste is always recorded by the differentiating meter, and may be readily localized by one of the methods described in Mr. Deacon's Paper already referred to.

The low rate of constant supply in two or three places—in which statutory power to interdict the use of existing fittings and pipes, and to prescribe the nature in detail of all new fittings, was obtained some forty years ago—has often been mentioned in support of the sufficiency of house-to-house inspection; the truth being that the condition was chiefly due to an almost complete re-construction of the works and fittings of distribution; and, however good that condition may be, it cannot be maintained without continuous detection and repair of flaws. The authorities of most of the places of which particulars are given in this Paper, possessed no such powers as these over the consumers' fittings and pipes. Undoubtedly it is desirable to possess them, but they need not be, and should not be, employed, except where persistent waste occurs from an existing fitting or pipe.

Although modern water-fittings leave much to be desired, they are generally excellent as compared with those of the past, but the desire for cheapness in first cost is still the cause of much waste and subsequent expense. Testing and stamping by the Water Authorities, when properly performed, is the only way known to the Author of maintaining a sufficiently high standard. The interests of different trades make it practically impossible in large communities to confine the plumbers to the use of fittings of a single type, and, indeed, with one exception, no single type of domestic water-fitting can be said to be manifestly better than another. That exception is certainly a notable one. By the invention of Lord Kelvin there is one practicably imperishable water-tap, on a new but now well-proved principle, without fibrous or organic washer of any kind. These taps are extensively used, though they cannot be produced at the lowest prices; but, where introduced, they entirely remove the constant nuisance and cost of leaking washers.

The principle of this fitting is so new that it deserves a detailed explanation. The tap is illustrated in *Fig. 3.* The washer A is of metal, and closes, as in other taps, upon a metallic seat. Metallic washers have frequently been tried in the past, but have always failed through the metallic surfaces becoming scored by the gritty particles which are occasionally found in all water; so that, when the washer is screwed down to the seat, either these particles prevent perfect contact and permit leakage, or else the water passes along the little furrows occasioned by their scouring action. In Lord Kelvin's tap, the washer is so arranged that, when it comes in contact with the seat, the handle is not suddenly arrested. The turning is permitted to continue somewhat beyond the point at which the flow ceases, so that at every operation of closing and opening the metallic washer is rubbed upon the seat. This is accomplished as follows:—The washer A is held in the can B by two gudgeons projecting from it, which are confined by the slots CC. The arrangement provides that whenever the can is turned the washer must turn also, and it further provides that the can may move parallel to its axis without moving the washer in the same direction. Pressing centrally upon the washer, is the hemispherical head of a rivet-shaped piece of metal, D, and upon the shoulder of the rivet-head the spring E presses. The can B being screwed into the body of the tap, it is clear that, upon closing the tap, turning may continue after the washer has reached its seat, so that burnishing of the surfaces takes place on every occasion of opening and closing.

Fig. 3.



Scale ⅔ full size.

Another remarkable improvement, also due to Lord Kelvin, is the abandonment of the usual stuffing-box for preventing the upward passage of water when the tap is open. At F there is an annular groove cut in the outside screwed portion of the can, and from a point in the body of the tap opposite to that groove there is a tube, G, leading into the outlet or "bib" of the tap. The water, in passing out, induces a current down the tube G, and so carries away any leakage rising between the screwed surfaces as high as the annular groove F. The result is that no water issues between the can and the body at J, and thus the necessity for a stuffing-box is entirely dispensed with.

There are some other peculiarities of construction which cannot easily be described. The improvements have now all stood the test of time, and the combination has resulted in a perfect piece of mechanism for domestic water-supply purposes.

[APPENDIX.

APPEN

Particular Examples of the Application and

Town.	Immediately before the Application of the System.			After the Application of the System.			Cost of Introduction of the System (Capital).	Annual Working Expenses.	Population.
	Year.	Service.	Average Daily Supply per Head.	Year.	Service.	Average Daily Supply per Head.			
			Gallons.			Gallons.	£.	£.	
Bath[1]	1885	Constant	47·70[2]	1890	Constant	21·00[2]	2,575	348	59,000
Birkenhead	1882	Constant	25·32[2]	1890	..	17·10[2]	3,059	473	92,947
Carlisle[3]	1877	..	42·56[2]	1890	..	18·80[2]	998	100	41,175
Gloucester	1883	Constant	32·00[5]	1891[6]	..	15 to 16[5]	2,000	169	37,000
Lambeth[7]	1880	Constant	33·00[2]	1890	Constant	18·34[2]	6,000	2,390	341,856
Leamington	..	..	24·00[5]	..	Constant	16·00[5]	370	112	22,797
Liverpool	1873	Intermittent	24·25[2]	1873– 1876 1890	Constant .. Constant	33·50[2] 20·25[2] 16·00[2]	 30,589	 3,068	 755,689
Portsmouth	..	..	35·00[2]	..	Constant	19·47[2]	..	..	111,300
Southwark & Vauxhall	1880	Intermittent Constant	29·00 50·00	1890	Constant	18·00	16,800	1,963	842,000[8]
Widnes	1886	Constant	11·29	1890	Constant	8·09	350	70	21,000
Yokohama	..	..	..	1891	Constant	15·4[9]	..	..	87,500

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[1] Approximate rate of intermittent supply with partial house-to-house inspection in 1881, 31 gallons per head per day.

[2] For all purposes including trades not supplied by meter.

[3] Before the introduction of the system, house-to-house inspection was employed and the rate of supply was 42·56 gallons per head per day.

[4] Of these, about 38,200 receive the public water-supply.

[5] For all purposes, including trades supplied by meter.

[6] In June, 1884, after 8 months' application of the system, the pressure on pipes and fittings increased from 40 lbs. to 60 lbs. per square inch, and the supply was reduced to 19 gallons per head per day.

[7] The system has been hitherto applied to 341,856 persons, out of a total population of 659,899.

DIX.

MAINTENANCE OF THE WASTE-WATER-METER SYSTEM.

Remarks.	Authority.	Annual Saving of Water.	Net Annual Saving to the Town, assuming Water worth 6*d.* per 1,000 Gallons, and Charging Interest and Depreciation at 8 Per Cent.
		Gallons.	£.
Waterclosets and baths general . .	Charles Gilbey . .	215,350,000	4,730
Waterclosets and baths general. Supply previously brought down from 35 to 25·32 gallons per head per day, by house-to-house inspection, and could not be reduced lower .	W. A. Richardson .	278,868,760	6,253
Waterclosets and baths general . .	J. Hepworth, M. Inst. C.E. . . .	364,240,800	8,926
Waterclosets and baths general . .	R. Read, Assoc. M. Inst. C.E. . . .	140,442,000	3,162
Waterclosets throughout, baths in about one-half the houses . . .	S. H. Louttit, Assoc. Inst. C.E. . .	1,858,437,285	43,591
Waterclosets and baths general . .	W. De Normanville, Assoc. M. Inst. C.E.	66,567,240	1,522
House-to-house inspection in operation in 1873, prior to application of the system	G. F. Deacon, M. Inst.C.E., J. Parry, M. Inst. C.E.	1,751,498,000	37,672
House-to-house inspection in operation prior to application of the system	H. R. Smith, Assoc. M. Inst. C.E. . .	630,898,485	
.. ..	J. W. Restler, M. Inst. C.E. . . .	3,372,600,000	81,008
Five per cent. of the premises have waterclosets and baths	.. ..	24,528,000	515
No waterclosets. Bathing very general	Major-General H. S. Palmer, R.E., Assoc. Inst. C.E.		

[8] The system has been hitherto applied to 648,600 persons, out of a population of 842,000.

[9] Waste less than 1 gallon per head per day, arising principally from taps out of repair, burst lead pipes, and fractures of service-pipes due to earthquakes. System in operation since the completion of the works in 1887.

NOTE.—It is impossible to assign to the water saved a uniform value per 1,000 gallons; but in this country a new supply can rarely be obtained for less than 6*d.*, and commonly costs 7*d.* to 9*d.* per 1,000 gallons.

A fair idea of the financial benefits resulting from the reduction of waste in the foregoing cases may therefore be arrived at by putting the value of the water at 6*d.* per 1,000 gallons, and by deducting the annual expenses, including interest and depreciation upon capital expenditure, incurred in introducing the system.

(*Paper No. 2627.*)

"Steam-Engine Governors, and their Insufficient Regulating Action with Extreme Variations of Load."

By Professor VICTOR AUGUSTE ERNEST DWELSHAUVERS-DERY,
of Liége University.

(Translated by BRYAN DONKIN, Jun., M. Inst. C.E.)

IN a former Paper[1] the Author proposed the following problem: How should a governor be constructed, so that the sleeve may rise to its highest position, when the velocity imparted to the engine during expansion is accelerated by the total suppression of useful resistance? At that time he expressed an opinion that, if it were possible to make any governor act in this way, governors with springs would alone be found sufficiently sensitive. He has since had reason to believe that they, as well as other better-known governors which he has studied, are too slow in action. The object of the present Paper is to explain the method followed in arriving at this conclusion; and the facts prové that the advantages claimed for certain governors are exaggerated, or without foundation.

The Author's method of proceeding was as follows:—He began by calculating the dimensions and weights of the governor that he intended to test, so as to make it "astatic," according to the meaning assigned to that term by the Author in a former Paper,[2] and as sensitive as the conditions of the problem required. He then traced the double diagram of the velocities of equilibrium during the rise and fall of the sleeve, in order to ascertain whether the instrument had any radical defect, and to remedy it if any. In the course of such investigations with regard to several tachometers, he concluded that the instrument best suited to the given circumstances was that which produced a point of inflexion in the diagram towards the middle of the stroke of the sleeve, a condition fulfilled by the Buss or Pichault governor.

Having carefully adjusted the governor, the Author endeavoured of expansion. The time occupied by expansion is determined by the calculations given at the end of the Paper; in the first case of variation in the load of the engine, defined in the previous Paper, it was 0·354 of a second. The sleeve was found to be much below its highest position; steam would therefore still be admitted during the next stroke, and the speed would go on increasing till the end of this stroke. The velocity attained by the engine, in spite of the retarding influence of the governor, could be thus calculated, and was about 5 per cent. above the mean. Following the same course, to determine the action of the governor in the second case of variation in the load of the engine, he detected a discrepancy at least as great in the contrary direction. The logical conclusion is, that the best governor cannot, when the greatest fluctuations in the load of the engine occur, prevent the velocity from varying by at least 10 per cent. The calculations below have, as in the former Paper, been based on the hypothesis of normal velocity, determined by experiments made on the engine in the Liége laboratory.

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[1] Minutes of Proceedings Inst. C.E., vol. civ. pp. 196 *et seq.*

[2] *Ibid.*, vol. xciv. p. 214.

Description and Calculation of the Governor Selected.

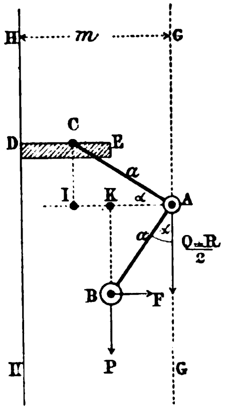


Fig. 1.

In *Fig. 1*, H H represents the centre-line of the governor, or the vertical axis of rotation, dividing it into two perfectly symmetrical parts, one only being shown in the drawing. An arm D E is fixed at right-angles to the axis H H, and the ball B at the end of a right-angled lever B A C. The point C is always kept on the horizontal line D E, and the point A on the vertical line G G, at the distance *m* from the axis of rotation H H. The two parts of the levers C A and A B are equal in length, and denoted by *a*. Two forces act at the centre of the ball,—the centrifugal force F in a horizontal direction, and the weight P vertically. At A, in the right-angle C A B, the sleeve is suspended. Half its weight is $\frac{Q}{2}$; and half the resistance of the communicating rods, $\pm \frac{R}{2}$, is applied according to the direction of the sleeve, whether tending to rise or fall. In any given position, the part A B of the arm of the ball makes an angle α with the vertical line, which is reckoned as a positive angle when the ball is to the left of the axis G G. With the sleeve in its middle position, the part C A of the arm is horizontal, the part A B vertical, and the angle $\alpha_0 = 0$. The extreme limits of the angle α are $\alpha_1 = 15^\circ$, and $\alpha_2 = -15^\circ$. On account of the special movements imparted to the points C and A, the instantaneous centre of rotation, for which the equilibrium of the governor should be adjusted, is at the intersection of the lines C I and A I, along the paths described. Equilibrium is obtained when the algebraical sum of the momenta of the forces F, P, $\frac{Q \pm R}{2}$, about the point I, is zero. The mass of the ball B has been so distributed about the centre of gravity, according to Buss's method, that it has been turned into a cosine pendulum, or, in other words, the momentum of the centrifugal force F, about the point I, is proportional to the cosine of the angle α. If u denote the velocity of rotation, the momentum is equal to $\frac{P}{g} u^2 m a \cos \alpha$.

The equations of the governor's equilibrium, as the sleeve rises and falls, will therefore be

$$\frac{P}{g} u^2 m a \cos \alpha = P a (\cos \alpha - \sin \alpha) + \frac{Q + R}{2} a \cos \alpha,$$

$$\frac{P}{g} v^2 m a \cos \alpha = P a (\cos \alpha - \sin \alpha) + \frac{Q + R}{2} a \cos \alpha ;$$

which may be written

$$\frac{2m}{g} u^2 = 2 - 2 \tan \alpha + \frac{Q}{P} + \frac{R}{P} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1),$$

$$\frac{2m}{g} v^2 = 2 - 2 \tan \alpha + \frac{Q}{P} - \frac{R}{P} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

Between the height y of the sleeve and the corresponding angle α, the relation is expressed by

$$y = a (\sin \alpha_1 - \sin \alpha) \quad . \quad . \quad . \quad . \quad . \quad (3),$$

and, if c represents the whole stroke, since

$$c = a (\sin \alpha_1 - \sin \alpha_2) = 2 a \sin \alpha, \quad . \quad . \quad (4),$$

it follows that

$$\frac{y}{c} = \frac{\sin \alpha_1 - \sin \alpha}{2 \sin \alpha_1} = \frac{1}{2} - \frac{\sin \alpha}{2 \sin \alpha_1} \quad . \quad . \quad . \quad (5).$$

Data of the Governor.

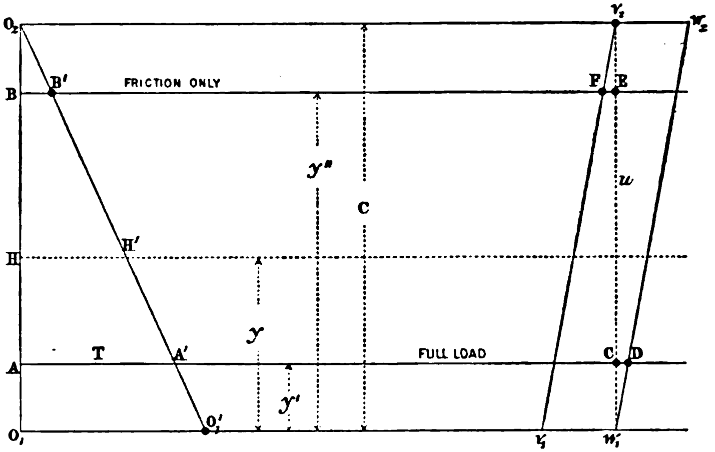
The extreme values of the angle α have been given above, viz., $\alpha_1 = 15^\circ$ and $\alpha_2 = -15^\circ$. In *Fig. 2* the total length of travel of the sleeve $0_1 0_2 = c = 0\cdot1888$ foot. When the sleeve has reached its highest point at 0_2, the steam admission is wholly cut off. When the sleeve is at A, where its height is $y' = 0\cdot0248$ foot, the motive-power per stroke is T foot-pounds, and is proportioned to the maximum useful load, at the mean speed of 61·21 revolutions per minute. In an intermediate position, H, the motive-power per stroke is in proportion to the distance of the sleeve from its highest position, represented by the abscissæ of the line $O_2 O'_1$.

Then

$$T_y = T \frac{c - y}{c - y'} \quad . \quad . \quad . \quad . \quad . \quad (6).$$

It has already been shown that, when the engine is running empty,

Fig. 2.



the work is equal to 0·17 of the work T with full load. Therefore the height y'' of the sleeve, which gives the mean speed when running empty, will be calculated by equation (5); in which $T_y = 0\cdot17$ T, $c - y' = 0\cdot1640$ foot, $c = 0\cdot1888$ foot, and $y = y''$ will be the unknown quantity, which is found to be $y'' = 0\cdot1609$ foot.

The absolute mean and other speeds of the engine are given; but, for the governor, the relative values of the speeds are known only compared with its mean velocity. Denote by w_1, w_2, v_1, v_2, the highest and lowest speeds of equilibrium of the governor during its rise and fall, and u its mean velocity at unit distance from the centre. To make the governor "astatic," which is the first condition, the necessary equation is

$$\frac{w_1}{u} = \frac{v_2}{u} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7);$$

and, to obtain the required sensitiveness,

$$\frac{w_2}{u} = \frac{62 \cdot 00}{61 \cdot 21} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8).$$

The value of $\frac{v_1}{u}$ must be next deduced from calculation, and, all other dimensions and weights having been determined, the values of $\frac{w}{u}$ and $\frac{v}{u}$ are calculated as functions of α, and represented by diagrams.

CALCULATION OF THE WEIGHTS AND DIMENSIONS OF THE GOVERNOR.

Among the data,

$$R = 2 \cdot 2046 \text{ lbs., and } m = 0 \cdot 7231 \text{ foot.}$$

Equation (4) gives

$$a = \frac{c}{2 \sin \alpha_1} = \frac{0 \cdot 1888}{2 \times 0 \cdot 258819} = 0 \cdot 3648 \text{ foot} \quad . \quad (9).$$

The highest and lowest velocities are given by the equations:—

$$\frac{2\,m}{g} w_2^2 = 2 + 2 \tan \alpha_1 + \frac{Q}{P} + \frac{R}{P} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10),$$

$$\frac{2\,m}{g} w_1^2 = 2 - 2 \tan \alpha_1 + \frac{Q}{P} + \frac{R}{P} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11),$$

$$\frac{2\,m}{g} v_2^2 = 2 + 2 \tan \alpha_1 + \frac{Q}{P} - \frac{R}{P} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12),$$

$$\frac{2\,m}{g} v_1^2 = 2 - 2 \tan \alpha_1 + \frac{Q}{P} - \frac{R}{P} \quad . \quad . \quad . \quad . \quad . \quad . \quad (13).$$

By combining equations (7) and (8) with these

$$\frac{m}{g} u^2 \left[\left(\frac{w_2}{u} \right)^2 - 1 \right] = \frac{R}{P} = 2 \tan \alpha_1, . \quad . \quad . \quad . \quad (14),$$

$$\frac{m}{g} u^2 = 1 + \frac{Q}{2\,P} = \frac{2 \tan \alpha_1}{\left(\frac{w_2}{u} \right)^2 - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15);$$

$P = 1{\cdot}866\ R = 4{\cdot}1138$ lbs.

$Q = 161{\cdot}5568$ lbs.

$u = 30{\cdot}303$, corresponding with $289{\cdot}37$ revolutions per minute.

The relation between the velocities of the governor and the engine is

$$\frac{289{\cdot}37}{61{\cdot}21} = 4{\cdot}73.$$

Lastly, v_1 is deduced from the equation

$$w_2{}^2 - v_2{}^2 = w_1{}^2 - v_1{}^2;$$

This velocity v_1, will be found to correspond to $60{\cdot}41$ revolutions per minute of the engine, so that the assumed coefficient of regularity of the governor may be taken at $\frac{61{\cdot}21}{62{\cdot}00 - 60{\cdot}41} = 38{\cdot}5$. The coefficient of sensitiveness is about double, or rather too great.

By introducing the several numerical values found above, into equations (1) and (2), the following values are obtained for the velocities of equilibrium w and v, as functions of α:—

$$\left(\frac{w}{u}\right)^2 = 0{\cdot}04846\,(20{\cdot}9035 - \tan\alpha)\ .\quad .\quad (16);$$

$$\left(\frac{v}{u}\right)^2 = 0{\cdot}04846\,(20{\cdot}3676 - \tan\alpha)\ .\quad .\quad (17).$$

From these equations, it is easy to see that the diagrams of the governor, or curves of w and v, are deflected in the middle of the stroke of the sleeve.

Having laid down the above propositions, the problem to be solved is the following: The engine, with a governor as described, is running at its normal speed with full load, the sleeve being stationary at the height $y' = 0{\cdot}0248$ foot. During the return stroke, just at the beginning of expansion, the whole of the useful resistance ($0{\cdot}83$ of the total resistance) is suddenly withdrawn, and the speed of the engine is accelerated up to $62{\cdot}84$ revolutions in $0{\cdot}354$ second, till the end of the stroke. Therefore, during the rise of the sleeve, the velocity of equilibrium w has been exceeded, and at the end of the stroke, when the governor can again act, the sleeve has reached a certain height. The problem is to determine this height.

APPROXIMATE SOLUTION.

The motive force which drives the sleeve upwards is the result of the difference between the real centrifugal force of the balls, due to the velocity W in proportion to the velocity V_a of the engine, and that due to the velocity of equilibrium, w, of the ascent of the sleeve. The work done between the two positions defined by the angles α' and α is equal to half the *vis vivâ* acquired by the masses P and Q, from the initial velocity (which is zero) up to the final speed $\left(\frac{d\alpha}{dt}\right)$. If the angle α' be 11° 0′ 35″, corresponding to $y' = 0 \cdot 0248$ foot,

$$\int_{\alpha}^{\alpha'} \frac{P}{g}(W^2 - w^2)\, m\, b \cos \alpha\, d\alpha$$

$$= \tfrac{1}{2}\left\{\frac{Q}{2g}\left(\frac{dy}{dt}\right)^2 + \frac{P}{g}(BK^2 + KI^2)\left(\frac{d\alpha}{dt}\right)^2\right\} \quad . \quad . \quad (18).$$

A solution of the problem from this equation is required; but it is impossible by pure mathematics. The velocity W is given as a function of the angle described by the crank of the engine, and w as a function of the height of the sleeve. Between the two a certain relation doubtless exists, but this involves precisely the unknown answer to the problem. By tentative calculations (*tâtonnements méthodiques*) a practically approximate solution may be found, which will serve as a basis upon which to found conclusions. The method followed below appears to be suitable for this purpose.

At the end of the stroke, the speed of the governor has become W_0, corresponding to 62·84 revolutions per minute of the engine, and the sleeve is at the height (y, α). When leaving the height (y', α') the sleeve has no velocity, because it only moves if the speed W exceeds w. Therefore from α' to α the motive power increases from zero up to a value proportional to $(W_0{}^2 - w^2)$; assuming that the variation is regular, and that the motive power may be considered constant, and equal to its mean value given by the factor $\frac{W_0{}^2 - w^2}{2}$. This quantity is taken from under the integral sign of equation 18; and, replacing the different symbols by their values, the following equation is obtained:—

$$\left.\begin{aligned}&\left(\frac{d\alpha}{dt}\right)^2\\ &= 4\frac{m}{a}u^2\left(\frac{W_0{}^2 - w^2}{u^2}\right)\frac{\sin\alpha' - \sin\alpha}{\left(6 + \frac{Q}{P}\right) + \left(2 + \frac{Q}{P}\right)\cos 2\alpha - 4\sin 2\alpha}\end{aligned}\right\} (19);$$

$$\text{or } \left(\frac{d\alpha}{dt}\right)^2 = 88\cdot 2 \, \frac{(0\cdot 84572 + \tan \alpha)\,(0\cdot 19091 - \sin \alpha)}{11\cdot 31778 + 10\cdot 31778 \cos 2\alpha - \sin 2\alpha} \quad (19).$$

The successive values of α are α', 9°, 6°, 3°, 0°, − 3°, − 6°, − 9°, − 12°, − 15°, and for each of these the values of $\left(\frac{d\alpha}{dt}\right)^2$ and of $\left(\frac{d\alpha}{dt}\right)$ are determined.

Having made these calculations, it is next required to find the time required for the sleeve to pass through the angle $(\alpha' - \alpha)$, assuming the velocity to be constant and equal to one-half $\left(\frac{d\alpha}{dt}\right)$. Clearly, the increase of speed is more rapid than in the uniformly-accelerated motion, and therefore the calculated time allowed is too long, but this will not invalidate the conclusions. The following Table gives the result of the calculation:—

α	$\frac{d\alpha}{dt}$	$\alpha' - \alpha$	t	$\frac{y}{c}$
			Second.	
+ 11° 0′ 35″	0	0	0	0·131
+ 9°	0·382931	0·0340093	0·1776	0·198
+ 6°	0·584525	0·0863692	0·2955	0·298
+ 3°	0·714985	0·1387291	0·3881	0·399
0°	0·811293	0·1910889	0·4711	0·500
− 3°	0·885957	0·2434488	0·5496	0·601
− 6°	0·944834	0·2958087	0·6262	0·702
− 9°	0·991037	0·3481686	0·7026	0·802
− 12°	1·026178	0·4005284	0·7806	0·902
− 15°	1·050857	0·4528883	0·8619	1·000

Hence it may be inferred that, after 0·354 second, that is to say at the end of the return-stroke under consideration, the sleeve will be at a height between $\frac{y}{c} = 0\cdot 298$, and $\frac{y}{c} = 0\cdot 399$, say, 0·362, corresponding to the angle $\alpha = 4° \, 59' \, 3.''$ The speed at this instant $\left(\frac{d\alpha}{dt}\right)$ is equal to 0·666937, and therefore the initial condition at the following stroke can be completely determined, and also the position of the sleeve at the end of admission.

The time of the next stroke will approximately occupy 0·47 second, and, as admission lasts during $\frac{58}{180}$ of the forward stroke, it will cease $0\cdot 47 \times \frac{58}{180} = 0\cdot 151$ second after the beginning of the stroke, or 0·505 second from the time of change of load. According to the above Table, the sleeve will then be at the height $\frac{y}{c} = 0 \cdot 510$. During admission, the sleeve has risen from 0·362 to 0·510, and is supposed to have regulated the work done, as if it had remained at the mean height 0·436, corresponding to $T' = 0 \cdot 65\ T$. Now, under ordinary conditions, the work $T = 6{,}942$ foot-lbs.; therefore $T' = 4{,}512$ foot-lbs. From this may be found the speed V_1 of the engine at the end of this stroke, given the velocity V_0 at the beginning, corresponding to 62·84 revolutions per minute, say 6·476 feet per second. The motive power T′ is 4,512 foot-lbs.; the work of frictional resistance is 1,295 foot-lbs.; 3,307·7 foot-lbs. remain to increase the motion of the fly-wheel, and

$$3307 \cdot 7 = \frac{M}{2}(V_1^2 - V_0^2) = \frac{3621}{2}(V_1^2 - 41 \cdot 938576).$$

Therefore $V_1 = 6 \cdot 6158$ feet per second, corresponding to 64·18 revolutions per minute.

It is easy to see that the sleeve of the governor will have reached the highest point before the end of this stroke.

Conclusion.

The governor cannot, during expansion, raise the sleeve to its highest point and cut off all admission of steam during the following stroke; therefore it cannot prevent an increase in the velocity up to 64·18 revolutions per minute, or a variation of $\frac{64 \cdot 18 - 61 \cdot 21}{61 \cdot 21} = 4 \cdot 85$ per cent. from the mean speed.

The second problem, that of throwing on the useful resistance at the beginning of expansion, when the engine is running empty at the mean speed, the Author has solved by the same process, and has been led to the conclusion that the governor cannot prevent a decrease of speed to 58·05 revolutions per minute, or a variation from the mean of $\frac{61 \cdot 21 - 58 \cdot 05}{61 \cdot 21} = 5 \cdot 16$ per cent.

The insufficient regulating action of the governor has thus been calculated to be 4·85 + 5·16, or 10 per cent.; but it must not be forgotten that extreme fluctuations of load and running have been chosen, which cannot often occur in practice.

Lastly, the Author desires to draw attention to the fact, that, In the first case, the engine must make more than [illegible] revolutions, and in the second case, $3\frac{1}{2}$ revolutions, before the normal velocity is restored.

CALCULATION OF THE DURATION OF EXPANSION IN THE FIRST CASE.

Number.	Speeds V. in Metres per Second.	Half the Space passed through, in Metres.	Products.
D¹	1·9191	0	0
12	1·9204	0·00305	0·01171048
13	1·9331	0·03290	0·12678015
14	1·9425	0·03020	0·11704312
15	1·9502	0·02945	0·11464002
16	1·9567	0·03010	0·11759769
17	1·9625	0·03205	0·12561036
18	1·9675	0·03620	0·14226600
19	1·9720	0·04555	0·17944422
19½	1·9738	0·03155	0·12448999
20	1·9741	0·07525	0·29707947
Totals .	..	0·34130	1·35666150

$$\text{Mean speed } \frac{1{\cdot}35666150}{2 \times 0{\cdot}34130} = 1{\cdot}958795 \text{ metre per second.}$$

$$\text{Duration } t = \frac{0{\cdot}6926}{1{\cdot}958795} = 0{\cdot}3536, \text{ say, } 0{\cdot}354 \text{ second.}$$

The Paper is accompanied by sketches, from which the *Figs.* in the text have been reproduced.

(*Paper No. 2640.*)

"The Use of Asphalt in Irrigation Works in California, U.S.A."

By GERVAISE PURCELL, B.A., Assoc. M. Inst. C.E.

THE Author has, in the course of his professional work in California, been for many years looking for a material that would be both economical and effective as an impervious lining for reservoirs in earth, and for the facing of earthen embankments. The common practice in California is to line such embankments with a coating of cement mortar, composed variously of one part of Portland cement to between two and four parts of sand. This plaster is from 2½ to 3½ inches thick, and is more or less effective, according to the age of the embankment it is applied to. Owing, however, to the absorption of moisture into the embankment during the wet season, and its evaporation during the hot season, the embankment subsides and fissures occur in the plaster coating which necessitate constant repairs.

As an alternative lining, the Author has experimented with asphaltic concrete, a material that is impervious and at the same time pliable, and might be expected to follow the unequal subsidence of the earthen embankment without cracking.

Before describing in detail the application of the concrete, it may be well to state what asphalt is, and where it is obtained. The principal mines are situated in the five counties of Southern California:—San Luis Obispo, Ventura, Santa Barbara, Kern and Los Angeles. In the first four counties it occurs in the eocene, and in Los Angeles county in the pliocene, formation. The asphalt beds are formed by the overflow of liquid asphalt or maltha, which is more or less mixed with sand, lime and earthy matters. By exposure to the atmosphere it becomes solidified, and is then refined to a uniform degree of purity by being heated in refining-kettles, until the sand and earthy matters are precipitated. By this operation between 80 and 90 per cent. of purity is attained. Too much asphalt should not be exacted from the purifiers, as, If the temperature is raised too high, variable elements are driven off, whereas too low a temperature allows some objectionable properties to remain in it. The products of the Arroyo Grande Mines, in San Luis Obispo county, are considered the best, when refined.

The Author experimented to ascertain the value of the asphalt mastic for the production of asphaltic concrete to be impervious, plastic, and to withstand the heat of the summer sun. A series of experiments proved that the best result was obtained from a mixture of 25 per cent. of sand, 75 per cent. of gravel in 100 lbs., added to 10 lbs. of asphalt mastic. The sand and gravel are put in at the upper end of a sand-drier, which is a horizontal cylinder 20 feet long, revolving in a heated casing, and come out at the lower end heated to the required temperature, viz., 310° F. The material is then run into the mixer, and the asphalt is added from a heating-kettle at a temperature of between 280° and 300° F. The mixer is a sheet-iron box with a semi-circular bottom, provided with a slide-door at the under side, and with an inside shaft, having arms so attached as to ensure thorough incorporation, and the coating of every particle of sand and gravel with the hot asphalt. The sand-drier and mixer are geared to a portable steam-engine, which supplies the power to revolve them. When the concrete is thoroughly mixed, the slide-door at the bottom of the mixer is opened, and the composition is allowed to drop into the wagon or barrow in which it is taken hot to the work. Asphalt mastic is made as follows: to every 100 lbs. of hard asphalt are added between 10 lbs. and 25 lbs. of liquid asphalt (specific gravity 11° Beaumé), free from water and volatile oils, below a temperature of 300° F., according to the hardness of the asphalt; and the composition is heated with moderate fires to 300° F. when it is used.

The asphaltic concrete is applied in a manner similar to that generally adopted in laying asphalt pavements; except that hand-tamping instead of rolling is resorted to, as it enables the workmen to compress the material better, and prevents the possibility of weak spots occurring. After tamping, a heated roller is run over the concrete while still warm, so as to smooth the rough surface and prepare it for the final coating, which is made and applied in the following manner:—To 100 lbs. of hard asphalt are added 3 lbs. of liquid asphalt, capable of standing a 300° "flash" test with specific gravity under 10° Beaumé; the whole is heated to 400° F., and the temper maintained by the addition of small quantities of liquid asphalt from time to time as the more volatile portion evaporates; to this is added between 10 and 20 per cent. of powdered carbonate of lime or sulphate of lime, according to the peculiarities of the asphalt. It is thoroughly stirred whilst being used, and is poured over the surface of the concrete and smoothed with a salamander, a heated bar of iron 2 inches in diameter and 8 inches long, with an iron handle. It is not advisable for the coating to be more than ⅛ inch in thickness, as, at that thickness, it maintains its shape, and answers all the purposes of closing the pores of the concrete, and rendering it impervious. The necessary machinery consists of two melting-kettles, one or more sand-driers, a mixer, a portable engine, and a boiler of not less than 15 HP. The gravel and sand must be as clean as possible, and the asphalt mastic of uniform purity and temper. Constant use of the thermometer is necessary, as variation of the temperature may spoil the uniformity of the work.

In a reservoir, lately completed by the Author, the capacity of which is 1,500,000 gallons, the depth 12 feet, inside slope 2 to 1, and outside slope 1½ to 1, with a top width of 6 feet; the floor was dressed to fall in all directions towards the outlet-pipe, which is laid under the floor in a bed of cement concrete to give it stability. The concrete is 3½ inches thick over the floor, and diminishes to 2½ inches at the top of the slope; the material was applied as described above, and has proved most satisfactory, the reservoir having stood full of water for five months without showing a flaw. The work was done, under the Author's direction, by the Asphalt-Paving Company, of Los Angeles, and under the personal supervision of their manager, Mr. Southerland Hutton.

A circular section of the material, 2 inches thick, was tested by the Author, under a pressure of 200 lbs. per square inch, and proved absolutely impervious. The cost of the work was 4*s.* 9½*d.* per square yard of surface coated.

(*Paper No. 2576.*)

"Wolverhampton Sewerage Works."

By Richard Evans Willoughby Berrington, Assoc. M. Inst. C.E.

The municipal borough of Wolverhampton comprises an area of 3,440 acres, and has a population of 82,620. Twenty years ago, the town authorities carried out a comprehensive scheme of sewerage and drainage, including the disposal of the sewage on the Barnhurst Farm hereinafter referred to. The works so carried out have amply justified the expenditure upon them; and there are now fewer deaths with the present population of 82,620 than there were when it amounted to only three-fourths of that number. It is perhaps hardly necessary to mention that Wolverhampton is an important centre of what is known as the galvanizing trade, in the operations of which considerable quantities of acids are used; and, owing to this fact and to its peculiar inland situation, the town occupies an almost unique position; for the watershed between the basins of the Trent and of the Severn passes through the town, its elevation is considerable, and only small upland brooks are to be found in its neighbourhood.

Barnhurst Sewage Farm.

The Barnhurst Farm, having an area of 330 acres, was purchased in 1870, and nearly all the sewage of the borough can gravitate to it. The Sewerage Committee attempted for many years to purify the sewage by means of broad irrigation over the farm, and also by intermittent downward filtration; but they ultimately found that for Wolverhampton sewage, precipitation of some kind was necessary.

From the outset the town has had two great difficulties to contend with: 1. The peculiar nature of the sewage, due to the presence of manufacturers' waste-water, which, even after treatment by them, still contains a great deal of iron and other matter. 2. The smallness of the brook into which the effluent has to be discharged—the natural dry-weather flow of this brook being considerably less than that of the sewage-effluent itself.

Oxide of iron in small quantities is said to be beneficial to land, but the application of raw sewage, containing a varying quantity of iron, soon gave evidence of being destructive to all vegetable life. It was found that, even when the sewage of fifty or sixty persons to an acre only was applied to land which had never been previously treated with sewage, the purification was most unsatisfactory, and this notwithstanding that the sewage percolated through between 4 feet 6 inches and 6 feet of soil. It is somewhat remarkable that oxide of iron, which has caused so much trouble and expense at Wolverhampton, is now being purchased and sent distances of over 100 miles for use as a sewage precipitant. But, while in the latter case it is under direct control, to be added to the sewage in definite quantity; at the Wolverhampton outfall it used to come down in an altogether uncontrollable manner. In fact, no precipitation-works could be made at a reasonable cost large enough to precipitate the whole of the iron, unless the manufacturers treated their waste-water (technically termed pickle) before allowing it to enter the sewers. This fact is evident in the ochreous condition of the brooks into which sewage has been run, where the pickle has not been previously treated by the manufacturers; and, when allowed to enter the sewers in an untreated state, it has baffled all efforts on the part of the local authorities to effectually precipitate it. This would not be so were strict compliance with the law insisted upon. In consequence of the difficulties above indicated, the riparian owners instituted legal proceedings against the Corporation, who pleaded guilty and agreed to pay damages; and, after a prolonged inquiry, the sum awarded amounted to one-tenth of that claimed. The riparian owners still continued dissatisfied, and, although the Corporation had promised to do all that science could suggest to remedy the then existing state of things, the town was nevertheless subjected to an amount of litigation almost without parallel in municipal history. There was first an injunction, then a sequestration order, and for several months the Corporation were in daily expectation that its mace and other property would be seized. After careful inquiry, the Sewerage Committee of the Corporation recommended, and afterwards the Town Council adopted, the following proposals:

(1) To exclude as far as possible all storm-water from the sewers, and

subsiding-tanks, and by means of other works to be constructed for the purpose on the Barnhurst Farm; and they instructed the Author to prepare the requisite working drawings and specifications for the same.

This was done without delay, and during the past four years the several works for that purpose have been successfully completed, and the town has been practically relieved from its sewage difficulties. The works recommended were:—1. A complete system of rain-water drains with outlets into the natural water-courses; 2. Precipitation works capable of being worked on the continuous or quiescent system; 3. Sludge-pressing plant; 4. Preparation of land for final treatment of the effluent.

OUTFALL WORKS.

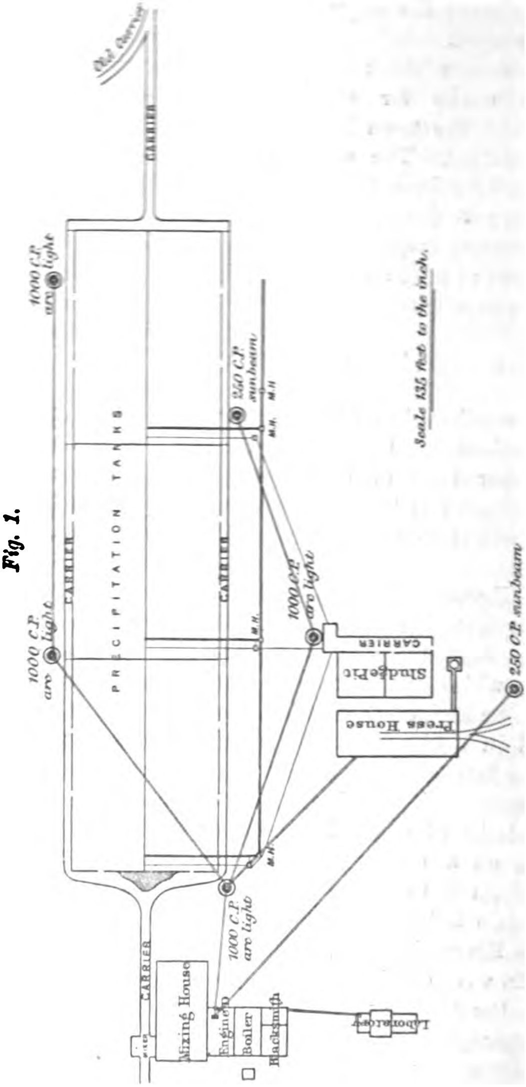
The dry-weather flow of the sewage is between 2,000,000 and 2,500,000 gallons per twenty-four hours, equal to between 25 and 30 gallons per head of the population. The water-supply for domestic purposes is 19½ gallons per head, and, including meter-supplies, to about 25 gallons per head. There is but little subsoil water.

The outfall works shown in *Fig. 1* consist of:—

1. Six precipitation tanks, each 150 feet by 50 feet, and between 5 and 6 feet deep, the whole being surrounded by an open carrier. The tanks, which are in two groups containing three each, are situated at the highest point of the farm attainable by gravitation, and extend in a direction parallel to the existing carrier which contours the farm; they can therefore be increased to any extent, and still command the land for purification purposes. The tanks are built of selected Tipton or Staffordshire blue bricks in cement, on a concrete foundation, and the walls vary in thickness from 2 to 2½ feet. The outer walls are coped with specially-made Staffordshire blue bricks, the centre wall being coped with Ferrumite flags, 3 feet wide. Both sides of the tanks are railed in with continuous iron fencing. When the sewage is treated on the continuous system, it passes into the first tank of one of the groups, and over each division wall, which is lower than the preceding one, until it reaches the carrier which conveys it to the different parts of the farm. When the quiescent system is in operation, the sewage passes along the carriers, and, by means of sluices, is made to enter any one of the six tanks as desired.

Each tank is provided with separate sludge- and effluent-pipes
Just before the sewage enters the tank it is thoroughly mixe

Fig. 1.


Old Carrier
CARRIER
1000 C.P. arc light
250 C.P. sunbeam
M.H.
PRECIPITATION TANKS
CARRIER
CARRIER
1000 C.P. arc light
M.H.
1000 C.P. arc light
CARRIER
Sludge Pit
Press House
250 C.P. sunbeam
1000 C.P. arc light
M.H.
CARRIER
Mixing House
Engine
Boiler
Blacksmith
Laboratory
Scale 135 feet to the inch.

with the proper proportion of milk-of-lime by means of a
agitator.

2. A mixing-house, 70 feet long by 30 feet wide. It is, perhaps, the largest in England for the size of the town; but experience has shown it to be not too large. For the present population one boat-load (about 25 tons) is used per week. In order to provide the men, who have to work in a place where quicklime dust is flying about, with plenty of space, so as to secure them as much air as possible, the building is 20 feet high and well ventilated. In this house there are three Bowes Scott and Read lime-mixing machines, with the necessary elevating-gear, and a horizontal steam-engine for working them.

3. An engine- and boiler-house, with smith- and tool-shop.

4. A Chemical Laboratory.

5. A Sludge-pit, 63 feet by 29 feet.

6. Ram-pits, 14 feet by 10 feet, and 9 feet by 9 feet, by 30 feet deep.

7. A Sludge-Pressing House, 78 feet by 30 feet; the machinery in which consists of a steam-engine, air-compressor and receiver, which are to be duplicated forthwith; two boilers; five Manlove sludge-presses (3-feet plates); and electric-lighting plant. Great difficulty was experienced in sinking the ram-pits 30 feet deep, as, after the first 12 feet, the remaining part of the excavation was principally in running sand.

The sludge from the precipitation-tanks gravitates to the sludge-pit, the supernatant water, which soon accumulates on the top of the sludge, being removed by a floating arm which is in communication with a small ram that elevates the water into a suitable outlet-pipe. The sludge gravitates thence into the rams, whence it is forced by compressed air, at a pressure of 100 lbs. to the square inch, into one or other of the presses. The floor of the press-house is laid with rock-asphalt. The platform is raised to a sufficient height to allow wagons to pass underneath the presses, and also to allow the expressed liquor to gravitate back to the main carrier, to be treated again, or, perhaps, to contribute something itself to the process of precipitation. The platform covers about two-thirds of the press-house, and consists of carefully-made concrete laid on girders, and overlaid with impervious asphalt. In sinking the ram-pits a considerable quantity of water was met with, and this is now pumped by the following somewhat unique method, which saves a large item yearly. The compressed air, after having been used as far as possible for pressing the sludge, instead of being then blown off, as is generally the case, passes into a large receiver; and, although of course its pressure is considerably reduced, there is still sufficient to work a small pump which lifts enough water for the several requirements of the works. The works are lighted by electricity; arc-lamps being employed for the tanks and other outside work, and glow-lamps for all inside lighting.

LIME.

In consequence of the iron always present in the sewage to a greater or less extent, the amount of lime used is very heavy, amounting on the average to 30 grains per gallon. It is hoped that when the true value of the waste pickle is realized, and some marketable commodity is produced from it, the quantity of lime required will be reduced by one-half—a saving which would have an effect of reducing the working-expenses by £1,000 a year. It was originally proposed to use lime and alumina, but the Borough Analyst considers alumina unnecessary on account of the presence of iron; and, generally speaking, no better effluent can be reasonably desired.

SLUDGE.

The wet sludge amounts to between 300 and 400 tons in twenty-four hours. This fact suggests how impossible it is to specify any treatment as universally applicable to the purification of town-sewage.

Cost of pressing wet sludge per ton	2½*d.*
Cost of pressing cake per ton	1*s.* 3*d.*
Average time of pressing	45 minutes.
Average time of filling, pressing, and emptying . .	1 hour
Average make per twenty-four hours	65 tons.

Containing 50 per cent. of moisture.

These figures are so remarkable as compared with pressing in other places that it was deemed desirable to further test their accuracy; but the additional experiments simply confirmed the previous trials. The cake is given to farmers and others free of charge, and at present there is a fair demand for it on those terms.

The Borough Analyst has furnished the following analysis of the cake, from 600 samples mixed.

——	Allowed to Dry in the Air until it would Powder and Mix.	Calculated into state as it comes from the Presses.	Approximate Constitution of Average Farm-yard Manure.
	Per cent.	Per cent.	Per cent.
Moisture at 212° Fahrenheit	26·70	50·00	75·0
Organic matter, &c.	20·70	14·12	17·0
Phosphoric acid	0·70	0·48	8·0
Lime	16·30	11·12	
Oxide of iron (FeO)	1·67	1·14	
„ „ (Fe_2O_3)	6·36	4·34	
Alumina	3·19	2·18	
Carbonic acid	11·60	7·91	
Magnesia, &c.	1·23	0·83	
Silicious matter	11·55	7·88	
	100·00	100·00	100·0

QUALITY OF THE EFFLUENT.

In consequence of the extraordinarily high-class effluent demanded under the peculiar conditions existing at Wolverhampton, the Corporation have retained the services of a resident chemist, and the precipitation- and pressing-processes are continued night and day. It is not represented that the clear effluent from the precipitation-tanks is fit to enter a brook, although in many large towns such a treatment alone is deemed sufficient to qualify the effluent to be discharged into a running stream. So far from this being the case as regards Wolverhampton, it is intended to acquire additional land so as to bring the total area in use up to about 400 acres, equal to 200 persons to an acre. This may be considered an unusual allowance in connection with a precipitating-process; but the standard of purity to be attained in the effluent is an unusually high one. The present area of land gives 538 persons to an acre; and Dr. Frankland, who was appointed by the Court to visit the works and report thereon, showed that the effluent was a very fair one; the Author therefore anticipates that when the new land is brought into use an excellent effluent will be produced.

Experiments have been made with "alumino-ferric," "ferrozone," and with the electric current. The "Amiens" process was also tried; but while both may be serviceable in special cases, neither offered any particular advantage when tried on the Wolverhampton sewage, nor exercised any marked influence on the effluent.

COST OF WORKS.

The cost of the works described in this Paper, including the sewers for the separate system, the precipitation-tanks, pressing plant, and underdraining of land, &c., has been about £30,000. This sum, of course, does not include the cost of the farm, nor of the main drainage works.

HOUSE DRAINAGE.

The Corporation, recognizing that no system of sewerage can work satisfactorily unless the house-connections are carefully made, now do all this work themselves at cost price, with the view of inducing the inhabitants to employ Corporation workmen. They have also established a depot where people can see modern sanitary appliances in actual operation.

THE PAN-SYSTEM.

No description of the sewerage of Wolverhampton can be complete without reference to the interception- or pan-system. Twenty years ago, the town was studded with cesspools. The pan was a cheap and ready means of enabling the town to get rid of the cesspools; and, considering that for the 17,300 houses in the town there are about 13,000 pans in use, the extent to which that system has been adopted is evident. In the Author's opinion, however, the pan-system is dirty and extravagant, and must ultimately be superseded by the water-closet, or waste-water closet. Undoubtedly a water-closet proper would be the cleanest, and will be adopted in all the best houses; but for cottage property, the waste-water closet would appear to be the cheapest, simplest, and least liable to get out of order. Several descriptions of these waste-water closets are now manufactured, and they are infinitely cleaner than the pan; they require but little repair, and they are rarely affected by the frost, whilst everything is carried away by the waste-water from the sinks.

Every pan emptied costs at least 2*d*. The contents are mixed with ashes and sold; but the sale is becoming difficult, and will soon be impossible. Moreover, the number of pans in use is increasing yearly; and, as the new houses are being built further and further from the depot, the expense of this system must be continually growing heavier. Ignoring the sales, therefore, and taking into account the continually increasing distance for haulage, 2*d.* per pan may be safely taken as the basis for the following calculations:—

PRESENT AND PROSPECTIVE COST OF PAN SYSTEM.

Year.	Pans to be Emptied. Total.	Cost at 2*d.* per Pan.	Cost of Water-Closets at 2*s.* 6*d.* a Year.	Cost of Waste-Water Closets.
1891	671,592	£5,596	£1,787	Nothing
1901	879,592	£7,329	£2,225	„
1911	1,087,592	£9,062	£2,662	„

Supposing the pan-system were stopped now, and waste-water closets supplied to new cottages, the saving effected by simply stopping the sale of pans would, by the year 1911, amount to £29,400. These figures have dealt simply with the prospective increase; but, supposing it were possible to abolish the pan-system in, say, one year, the financial result would work out as follows:—

	£.
Saving by an immediate change of the pans in use to-day .	111,920
Saving by the adoption of waste-water closets from 1891 to 1911 for new houses	29,400
	141,320
Deduct cost of changing present pans	26,000
Net saving in twenty years . . .	115,320

The abolition of the pan-system, then, would save the town, in twenty or twenty-five years, upwards of £100,000, and at the same time improve the health and well-being of the people.

One would expect to find that, in towns having an interception- or pan-system, the water used per head would be much lower than in water-closeted towns; but it is not so. In Wolverhampton, the estimated consumption per head for domestic purposes only is 19½ gallons per day. Actual measurements by meter in various houses made by the Author and others in different provincial towns, prove that, for cottage property, the quantity of water really used does not amount to more than 4 or 7 gallons per head, and in larger houses between 7 and 16 gallons. Where a daily bath was taken, and with two water-closets, the consumption often fell below 20 gallons per head.

It is fair to assume, therefore, that a well-regulated water-carriage system could be maintained with the present consumption of water, and reduced waste; which, notwithstanding the efforts of Mr. G. F. Deacon and other members of this Institution, still takes place to a large extent throughout the country. Much of this waste is hidden, and is simply finding its way to the basements of houses—working injury to both property and health.

In regard to the sewerage of the borough, the Corporation has, at different times, consulted the late Sir Joseph Bazalgette, Mr. Henry J. Marten, Mr. Edward Pritchard, MM. Inst. C.E., and Mr. Alsing, Assoc. M. Inst. C.E., and their assistance has been of the greatest value in effecting a satisfactory solution of the question.

The communication is accompanied by a plan, from which the *Fig.* in the text has been prepared.

(Paper No. 2626.)

"La Guaira and Caracas Railway."

By Edwin Harry Alfred Heinké, Assoc. M. Inst. C.E.

(Abstract.)

This railway runs from the port of La Guaira on the Caribbean Sea to Caracas, the capital of the republic of Venezuela, which is a city of about 75,000 inhabitants, at an altitude of 3,000 feet above the sea-level. The distance is only $22\frac{3}{4}$ miles, and in order to attain this elevation the line has had to be built with a ruling gradient of 1 to $26\frac{2}{3}$ (3·75 per cent.), rising to a height of 3,200 feet shortly before reaching Caracas, and then falling 200 feet to the terminus; the chief peculiarity of its construction being, however, the extreme sharpness of the curves and counter-curves, the generality of which have a radius of 250 feet, while one has as little as 140 feet radius. The railway is indeed a wonderful feat of engineering, and the difficulties attending the working of the line are almost unique.

The line is a single one, with sidings for the passage of trains that meet. Its gauge is 3 feet, and the traffic, of which by far the largest portion is up-grade, is hauled by locomotives without any centre-rail. When the coffee-crop is a poor one there is little or no traffic down to La Guaira, and many wagons go down empty. The track winds up the mountain side with yawning precipices on one side and enormous heights towering above it on the other. In some places it runs through cuttings 70 feet deep, alternating with short tunnels, of which there are eight, bored through the solid rock, the longest being about 120 yards in length; and the continual twisting and turning on the steep gradient, and on the edge of precipices, where there is sometimes a sheer drop of 1,200 feet, is alarming to passengers when first travelling by it. It is said, without much exaggeration, that the two ends of the train sometimes approach so closely that the conductor on the last carriage can whisper into the driver's ear; and Monsieur de Lesseps, after travelling upon it, remarked of the line, that there was only one dangerous point on it, but that was a continuous one for the whole distance from La Guaira to Caracas. It is, nevertheless, the fact that, notwithstanding the really dangerous character of the railway, there has not been a single accident to passengers during the eight years it has been in existence, and only one case of a break away on a goods train. This, however, is due to the unceasing vigilance of the employés, who know that they carry their lives in their hands, and also to the use of a very effective brake.

Owing to the sharpness of the curves, the driver often cannot see 20 yards in front of him, and men called "vigilantes" are stationed at intervals all along the track on the look out for impediments, and for any threatening slip of earth, their duty being, in the event of danger, to notify it at the nearest telegraph, the whole of the working arrangements, and of the meeting of up and down trains being conducted through the telegraph offices. Excepting at the Caracas station, there are no signals on the railway.

The landslips are very frequent during the rainy season, which practically lasts about six months. As many as two hundred and two have been known to occur during one night, and this is a constant source of danger. Sometimes the trains have been imprisoned for three days between two huge landslips. On one occasion, the slips were so numerous, that on the whole track there were not four hundred consecutive yards of clear line remaining unencumbered, and the traffic was stopped for a fortnight. On another, two bridges were washed away, and a third much injured, and the traffic was interrupted for a week. Many of the cuttings were originally made with slopes which approached the perpendicular, although half of them are in loose earth, without any rock support. The present manager, Mr. George Ross is, however, making great improvements.

The plan he has adopted is to cut away the outside wall of those cuttings which are near the edge of the mountain side, leaving the road on that side exposed. Then, when slips of earth occur from above, the rubbish is expeditiously removed by shovelling it over the edge of the precipice, instead of having to haul it out at one end or other of a deep cutting. This, at the same time, widens the track, and facilitates the eventual addition of a second line of rails.

It has been found necessary, with the very sharp curves on this line, to give more super-elevation to the outer rail than the regular formula warrants, in some cases, as much as 4½ inches; and the Author was surprised to see it recently stated (*Engineering*, Dec. 25th, 1891, p. 753), that a Committee of French engineers appointed by the Minister of Public Works, among other conclusions, had decided that super-elevation of the outer rail in curves, even when running at high speeds, was unnecessary, and in fact a cause of instability rather than otherwise.

As originally constructed by Messrs. Perry and Co., the line had rails of 40 lbs. per yard; but these are now being replaced by steel rails weighing 50 lbs. to the yard, and 24 feet in length, single-headed, of the Vignoles section, and spiked to sleepers made from an extremely hard and durable wood of the country called Vera (a species of greenheart), 7 feet long by 9 inches by 4½ inches, and 2 feet apart from centre to centre.

The quantity of locusts which infest the line is so great that they frequently stop the trains. Even when only a few are crushed, the rails and wheels become so greasy, that all adhesion is destroyed, and they slip to such an extent that the trains often run back down the incline. Experiments have been made to clear the rails of them by means of a steam-jet, and also by fixing brushes on to the cow-catcher; but owing to the sharpness of the curves, and the frequent reverse-curves, neither plan has proved of much use. The only remedy at present in use is sanding the line, placing a man for the purpose in front of the engine; but the platelayers have orders to do the same wherever the locusts are thickest, and also to brush them off the rails as much as possible.

The nature of the line limits the number of vehicles that can be hauled to a very small number. The goods trains are composed of three wagons nominally loaded with 10 tons of freight, although usually carrying more; the average weight of the train, including tare of wagons, but exclusive of engine, being 45 tons. On one occasion, however, with a new engine, a load of as much as 95 tons has been hauled from La Guaira to Caracas.

The passenger trains consist, as a rule, of four coaches and a van, but even this number, especially when there are locusts on the line, occasions trouble on the sharp curves, the length of the train causing a strain across the chord of the arc, or curve, which is very severe upon both the line and the rolling-stock.

For fuel, patent blocks (Crown brand) are used, it having been found that Welsh coal destroyed the fire-bars too quickly. These blocks cost at La Guaira, £1 18*s*. per ton, and are admitted free of Customs duty. Experiments several times repeated have shown their evaporative efficiency, with the locomotives used on this railway, to be equal to 8 lbs. of water per pound of fuel; but the consumption varies much according to circumstances and to the skill of the drivers; the present average, taking engines and drivers all round, is about 60 lbs. per mile.

A variety of causes add to the working expenses of the line. The large quantity of sand which penetrates the machinery requires the brasses and other parts to be refitted every three weeks, and causes so much wear and tear of the tires that those of the bogies have to be renewed every six months. Leakage of the boiler-tubes is continual and very troublesome. This the Author attributes partly to the high pressure of from 145 lbs. to 160 lbs. on the square inch, which causes a continuous strain during the up-journey, and partly to the successive shocks which the engines sustain almost every minute as they pass from one curve to another; for notwithstanding the slow speed at which the trains run on the average (two hours being allowed for the 22¾ miles), the passenger trains attain at times a speed of 18 miles an hour. The shocks shake down the fire-brick arches, which rarely last more than two weeks, so that a large stock is required for renewals.

The engines are eighteen in number, and are practically all of the same type. That now adopted is the simple, six-wheel coupled outside cylinder tank-engine, with a bogie at the trailing end, weighing, when in working order, from 34 to 35 tons. The tanks hold 600 gallons of water, and the coal-bunkers 1 ton of coal, some of the blocks of patent fuel being packed in addition on the foot-plate, and on the top of the tanks. The cylinders are 1 foot 3½ inches in diameter, and 1 foot 8 inches length of stroke; the wheels, 3 feet in diameter, thus giving a tractive force of 133·5 lbs. for each pound of effective pressure per square inch of piston. The engines are provided with a steam-brake and with a hand-screw brake. The coupled wheels are brought as close together as possible, the centre ones being without flanges; the brake-blocks are applied to all six wheels. The driving- and centre-wheels are ¾ inch, and the trailing-wheels 1 inch slack to gauge; the bogie has a lateral play of 3 inches on each side, the wheels being 1 foot 10½ inches in diameter, and the tires 2½ inches thick by 5½ inches wide; those of the pony-trucks are 2 feet 7 inches in diameter.

The carriage and wagon stock consists of twenty-one coaches of first and second class, five vans fitted with postal, luggage, and guards' compartments, and one hundred and ten wagons which are of four classes, viz., covered, open, platform, and timber wagons, all of the bogie type. It speaks well for their workmanship, and the attention bestowed upon them that, in spite of the severity of the line, a hot box rarely occurs.

The first-class carriages are 24 feet long by 7 feet 6 inches wide; the second-class (seating twenty-five passengers), 21 feet long by 7 feet 6 inches wide. The wheels, both of the carriages and of the wagons, are 2 feet in diameter, and are interchangeable, required.

All the carriages and wagons are supplied with a Heberlein brake, but worked from the engine only, an extra man being placed on the foot-plate for this purpose; the same man also attends to the sanding of the line when locusts are numerous. Most of the stock is also fitted with a hand-brake, but this is rarely used, reliance being placed, as a rule, on the Heberlein friction brake.

The railway has a constantly increasing traffic both in passengers and goods, and whereas formerly it was considered a good day's work to bring up from La Guaira twelve freighted wagons, now as many as forty-two are frequently taken up.

(*Paper No. 2632.*)

"Improvement of the Entrance to Otago Harbour, New Zealand."

By George Morrison Barr, M. Inst. C.E.

The harbour of Otago, situated on the south-east coast of the Middle Island of New Zealand, has for the last thirty years been the principal port in the colony for imports, though it is now closely followed in that respect by Auckland and Wellington, while Lyttleton far exceeds it in exports. This port is an arm of the sea, bearing north-east and south-west, 15½ miles long, and averaging 1¼ mile in width. Two islands about the mid-length divide it into the "upper" and "lower" harbour, upon the former of which, at its southern extremity, stands Dunedin, the chief town of the district of Otago, and at the inner end of the latter is Port Chalmers. In the earliest days of the settlement, all large vessels anchored inside the Heads near Harrington Point; next they were accommodated at Port Chalmers, and, since 1884, a large proportion of the ocean sailing-vessels, and almost all the inter-colonial steamers, have berthed at Dunedin; but the large steamers trading between the colony and Britain still load and discharge at Port Chalmers. The increase in the shipping at Dunedin since 1884 has resulted from improvement works in the upper harbour, A, (Plate 2, Figs. 1 and 2). This Paper, however, deals especially with the natural condition of the entrance, and the works carried out for its improvement.

Physical Features.—The harbour is bounded on each side by volcanic hills, reaching an altitude of 2,200 feet on the north-western side, and 1,500 feet on the opposite side. Its south-west extremity is separated from the South Pacific Ocean by a stretch of flat, low-lying land, 1 mile wide at its narrowest part, bounded at the ocean beach by a fringe of sandhills, rising in parts to 50 or 60 feet above the water-level; but at other places, the ground is so low as occasionally to be inundated by the sea during high tides with heavy gales. This flat land is due to ancient deposit, which is of considerable depth, indicating that, at some remote epoch, the "Peninsula" was an island, and the site of the present harbour was a tidal strait. Probably the chief agencies of the closure of the south-west extremity of the strait, instead of the north-western one, were (1), the exposure to stronger seas, which would drive the sand, borne by the flood-tide, into the deeply recessed and well-sheltered bay lying between Forbury Head and the site of Dunedin, where it would remain; (2), the contiguity of soft sandstone cliffs on the west; and (3), the discharge of large quantities of gravel, boulders, and clay, the waste of the high lands, brought down by the water of Leith stream.

All the circumstances of this locality suggest that the formation of the flat lands, marked B (Plate 2, Fig. 1), which are all alluvial, was commenced at a very early time, and also that the formation of the bar in its recent position was mainly due to the presence of that portion of land. Both before and after the closure of the south-western extremity, there would be a tendency towards accumulation of sea-drift at that position, for it would be carried on to the old beach, at the base of the volcanic rocks, by the direct force of the waves. A flat of similar formation exists at Purakanui Bay, about 5 miles to the north, which has been formed at the mouth of a deep indent in the volcanic hills, and which could not have had another opening. There is, however, no off-shore bar at Purakanui similar to that at Otago, probably because the amount of tidal water issuing from the bay, which is only about one-hundredth of that passing Otago Heads, is too small to arrest solids in suspension at any distance outside the line of the beach. This flat, B, has been formed upon a gravel beach, similar to what is found at many parts of the harbour, a portion of which was disclosed when the sand was cut into in clearing for quarrying. Once this began to form as a projection from the western cliffs, the stream would tend to keep towards the concave side at the peninsula, and thus leave the convex side in comparative quietude, when the tendency to further deposit would be strengthened. Thus the sand point would continue to stretch across the channel, until it reached a point beyond which it could not advance without reducing the cross section for the passage of the tidal waters to a limit necessitating a rate of current so strong as to scour the sides and bottom. But whatever were the stages of its growth, by the time it had attained its present shape, it had brought the tidal currents into such a direction, and had given them such a strength, as to favour the formation and growth of the bar. By stretching seawards, it had pushed the balancing line between the strength of the tide and the ocean wave further in that direction, and at the same time it would co-operate with the rocky formation on the opposite side of the channel, in giving that oblique direct to the ebb current which has been a powerful factor in shapi the bar.

The prevailing winds are from the north-east and south-w the result probably of the general direction of the Middle Isla The register of Dunedin for ten years, and also for the exceptio year 1886, is as follows:—

Period.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm	Gale
										N.E.
Average per annum from 1876 to 1885 .	8	66	13	10	11	102	38	7	110	5
1886	12	93	7	21	13	114	13	12	80	14

It is high-water at the Heads at two hours fifty minutes full change, and about one and a half hours later at Dunedin, un ordinary conditions of weather. The winds greatly influence tides, both as regards their height and their rate of travel. level at Dunedin frequently differs by a few inches from tha the Heads; and on one occasion, when the current of the flood impeded by a severe south-west gale, the deficiency at Dun compared with Port Chalmers was 13 inches. Under ordi circumstances, however, the tide rises to the same height at southern and northern ends of the harbour; but as the ebb commenced at the Heads before it is high-water at Dunedin, estuary is never quite full, being deficient by a wedge 6 or 8 in thick at the one end. The range of an ordinary spring-tid 6½ feet, and of a neap-tide 4¾ feet; but under the influenc strong easterly winds, a neap-tide may reach the height o ordinary spring-tide; and, with the opposite winds, a spring may be much below the standard level, whilst with westerly w it occasionally rises to 8 feet.

The area of the estuary is a little over 12,000 acres, of w 3,200 are beach and bank, dry at low-water. Making allow for these banks, and also for the wedge by which the level of flood-tide is deficient throughout the harbour, 113 million c yards of water travel out and in with a standard spring-tide, rather more than 82½ millions with a neap-tide; 240 acres of beaches have been reclaimed, principally in Dunedin, but pa along the western side in the upper harbour, and to a small ex at Port Chalmers, amounting to one-fiftieth of the water are

1870 the Author reported to the Provincial Government of Otago, when the area reclaimed was about 42 acres, reducing the volume of a spring-tide by about one six-hundredth, and, while expressing the opinion that this could not prejudicially affect the bar, he insisted upon the limitation of these operations to what was absolutely necessary. Since that date the Colonial Government has reclaimed about 60 acres for a railway station, and the Harbour Board has reclaimed 100 acres for revenue purposes; but there is nothing to show that the exclusion of the tidal waters by these works has reduced the scouring agencies of the tide to an appreciable extent.

The heaviest seas come from the east and south-east, often with light winds, and sometimes with calm weather, so that the waves which reach the coast must be the propagation of storms far out at sea. They come direct on to the beach, and not with the oblique action so noticeable further north at Timaru. A north-east wind, to which the harbour entrance is exposed, brings a short lumpy sea with little force, and the south-west, being off the land at the Heads, makes a smooth bar. The easterly seas of August-September, 1886, reduced the beach to the west of the training wall, and also at the ocean beach near Dunedin, while it made up the bar to some extent, and also caused large accumulations of sand on the beaches to the south-west of Heyward Point.

Natural Changes, 1850 *to* 1891.—The earliest survey of the harbour was made by Captain Stokes in 1849-50; and the next was by Mr. D. L. Simpson, M. Inst. C.E., the upper harbour in 1875, and the lower in 1879. A comparison of these two shows that the low-water levels adopted at the different times were practically the same; and it does not disclose marked changes, except at one or two places. In the upper harbour, a cross section in front of Dunedin shows an average shoaling of 12 inches, a not unlikely occurrence in thirty years. In the lower harbour, the first survey showed a sandy shoal about a mile inside the Heads (known as the inner bar), with only 15 feet of water over it at low tide; while the second survey gave, at the same spot, a good channel with $27\frac{3}{4}$ feet of water. Between that and Port Chalmers, Captain Stokes showed a limiting depth of 20 feet, and Mr. Simpson $23\frac{3}{4}$ feet. This shoaled up again to 20 feet within the last five years, and has been temporarily improved by dredging. On the outer bar, the Admiralty chart showed 16 feet, and the later map 15 feet on the line of leading beacons; but taking the average of the soundings along the ridge, the two surveys agree. Comparing the breadths, however, at the different times, the distances between the 18 feet contour lines are slightly greater in the more recent survey; and the western point of the bar has travelled about 24 chains nearer to the beaches in the interval. The limiting depths in the north channel fell from 22½ to 20¼ feet, and the average from 29 to 26¼ feet, indicating a period of deposit during these thirty years. The close similarity between the bar soundings of these two surveys, is more a coincidence than a representation of the general depths during the intervening time, for the records kept by the harbour-master's staff show that large variations were experienced. For instance, there were 19½ feet of water in August and October, 1872, on the line of the leading lights; but in 1879, the depth fluctuated between 15 and 16 feet; and in other years, the soundings were between these extremes. Between 1879 and 1881, when dredging was commenced, the depths ranged from 15½ to 16½ feet. The bar was generally better with a prevalence of strong south-west winds, which brought high tides, and also made a smooth bar.

On the 13th August, 1868, there was a severe earthquake in Peru and Ecuador, which, on the 15th, caused a violent disturbance of the sea on the coast of New Zealand. At Otago Heads the wave rose 1 foot higher, and fell 18 inches lower than the mean high- and low-water, or about 18 feet in all; and it kept swelling and receding with diminishing range for about twelve hours. At Port Chalmers the vertical oscillation was 15 to 18 inches; while at Dunedin there was only a slight throbbing. The extra currents reduced the northern part of the bar, from an average depth of about 15½ feet down to 22 feet at low-water, and probably displaced about a million cubic yards of sand from that part, while it heaped up immense quantities on the part to the eastward; so that, in the line of leading lights, the depth was suddenly reduced to 11½ feet, and consequently vessels had to approach and leave the harbour by the north channel. In about two years, the bank had resumed its old shape, showing that whatever agencies had built it up in the first instance, the forces which produced its modern form were still in existence. These disturbances of the waters did not affect the inner bar.

No part of the harbour has shown so many changes from natural agencies as that portion lying between the Kaik jetty and Harrington Point. The ebb-tide runs strongly towards the concave eastern beach, causing the spit on the opposite side to stretch in the same direction, until the bend becomes so acute that the main strength of the flood-tide makes a shorter cut for different routes with an area of almost still water between them, where the deposit of sand forms a bank in mid-channel. Probably that is the history of the inner bar, which, being little more than a knoll, must have been the remains of a larger shoal, and has its existing representative in a bank near the old locality, which has been created in this manner within the observation of the Author.

In 1850, the channel was very crooked, and the inner bar formed a serious obstacle to navigation; but there were narrow gullets of 18 and 19 feet on each side of it. An attempt to remove this by harrows about 1864, only resulted in the reduction of a few unimportant knobs; and when the Author inspected it in 1870, there was only 15 feet on it at low-water. However, in 1872–4, nature diverted the main volume of the water towards the east, causing the ebb-tide to scour away the obstruction to a depth of 27¾ feet by 1879. From this date, the spit was travelling eastward, and by January, 1887, the flood-tide seemed likely before long to take a more direct course; and this appeared so imminent in June, that the Author drew the attention of the Harbour Board to the circumstance. In 1888, the flood channel developed still further, and simultaneously a bank grew up in the area between the two streams with only 16¾ feet, where five years earlier there was a depth of 30 feet; and by April, 1890, the depth was only 14 feet 5 inches, whilst the flood channel still deepened on the west, and the ebb current followed the eastern side. The sailing course consequently became exceedingly difficult for the outward passage of long vessels; and the Harbour Board dredged a channel in the line of the flood current, which, by April, 1891, gave a low-water depth of 20 feet; but the bank had shoaled to 13 feet 5 inches at one point, with larger areas ranging from 14⅔ feet to 15¼ feet, producing a somewhat similar channel to that of 1850 to 1872, but not quite so bad. On the eastern side, there has always been a back channel, with a bank between it and the main one, having depths at low-water of 17 to 30 feet in the channel, and 2 to 6 feet on the bank in 1850; 16 to 20 feet, and 8 to 10¼ feet respectively in 1883; and 15¾ to 24¾, and 4 to 6 feet respectively in 1891, and between these depths in other years. The principal depths did not appear to vary much between 1850 and 1871; but about 1871 a scouring action commenced at the bank, probably due to the same cause as the scouring away of the inner bar. The cross section Y Z (Plate 2, Figs. 4 and 7) shows the alterations between February, 1885, and April, 1890, and indicates the form and position of the channel being formed towards the west by the flood-tide. In this period, the average low-water depth had increased by 3⅓ feet, its width had decreased 693 feet, and its area had increased 329 square feet.

From 1879 to February, 1885, along a line 500 feet seaward of Y Z (Plate 2, Fig. 1), the average low-water depth had increased 6 inches, its width had decreased 211 feet, and its area had decreased 1,470 square feet. This reduction in the sectional area, though larger than between 1885 and 1890, is still only 3 per cent.; whilst between 1850 and 1879, there was an increase of only 3½ per cent. Therefore, whatever differences arise in regard to the widths and depths, the areas of the cross sections keep fairly constant. Sir John Coode, Past-President Inst. C.E., pointed out that one effect of the construction of the two breakwater moles, recommended by him, would be the reduction of the eastern margin of the north spit, by the flood-tide being made to act more strongly upon it; and possibly the formation of this new flood channel has been promoted to some extent by the portion of the scheme which has been carried out; but the Author is of opinion, that even if these works had not been commenced, the time had arrived when the flood current would have cut across the spit, in preference to travelling by the longer and more tortuous channel of the ebb. It is not unlikely, however, that the movement of the outer part of the spit further in towards the harbour in 1887, was caused by the new strength given to the flood current. Once established in its new position, the power of the flood to scour its channel would probably be about the same as in the old position, but a little further seaward.

The Author anticipates that the ebb-tide and the north spit will cause the dredged channel to be silted up; and he has advised the construction of a rubble training wall approximating to the 18-feet contour line, going north-eastward from about the Kaik jetty, so as to force the ebb over to a position nearly coinciding with the route of the main body of the flood. A groyne is also suggested about ½ mile further south, for the purpose of blocking off the water from a back channel which has low-water depths of 20 to 32 feet, and which ought to be continued to join the longitudinal wall if funds will allow.

SCHEME FOR IMPROVEMENTS.

In May, 1880, the Author pointed out the conditions of the currents near the Heads, and urged the desirability of blocking up the north channel for the purpose of deflecting these; but the first recommendation in this direction put before the Harbour Board was in a report from Sir John Coode, received in June, 1880. In that report, the expectation of getting an improved permanent channel by dredging alone was discouraged, and the general principles of improvement by induced scour were laid down; and plans showed the direction of two breakwater moles, and of an improved line of channel inside the Heads; but in the absence of information upon the currents and the composition of the bar, no details were given (Plate 2, Fig. 7).

The Author having become engineer to the Harbour Board in May, 1882, immediately urged the desirability of building the western wall across the north channel, believing that while the complete scheme of Sir John Coode was beyond the capability of the Board at the time, this work would turn the currents into a better direction, and with the rocky headland on the eastern side, would concentrate the tidal forces within reasonable compass. A survey of the harbour entrance was accordingly made in January, 1883, including a series of soundings over the lines of 1879; and these were repeated at frequent intervals till November, 1888, when the works were stopped, and the Author ceased to be engineer. Since then, these soundings have been continued on the same lines, and in the same manner, by the inspector of works.

Conditions in January, 1883.—While the flood-tide enters the harbour with its main force in the most favourable direction for the channel across the bar, the strongest ebb runs almost due north, obliquely to the bar, and therefore, favourably for counteracting the heaping-up agency of the ocean wave. The greatest velocity of the flood was 1¼ knot per hour, and of the ebb 2 knots per hour. The deepest water followed a somewhat tortuous line along the North Channel, which had the serious disadvantage of taking a vessel beam to sea; and at one part, the channel was dangerously close to the beach. Besides these currents, one ran constantly from the north-west, parallel to the beach, about ten chains wide, apparently independent of the tides, but probably running towards the main body of the ebb as it left the harbour, or of the flood as it entered. When this was stopped by the construction of the training wall, the beach began to extend upon the north-west side, owing to the increased deposit in the quieter water.

The 18-feet contour line of the bar had a convex outline towards the sea on the northern part, and a concave form next the beach;

but adjoining the line of leading lights, close in upon the shelter of Taiaroa Head, parallel to the strongest ebb, but directly across the strongest flood as it comes sharply round the headland, the concavity is on the ocean side. The narrowest point of the bar was also in the line of beacons, where the flood was relatively stronger than the ebb. At this part, the distance between the outer and inner 18-feet contour lines was 400 links; while further north, on the line of the strongest ebb, the distance between the same lines was slightly over 20 chains. In this latter position also, the least depths, of only 12½ feet, were found, when there were depths of 16 feet of water in the sailing channel. Where the bank tapers off and merges into the North Channel, neither tide preponderates.

The inner slope of the bar, between the rocky face of Howlett Point and the line of beacons, is decidedly steep (Plate 2, Fig. 3). For 6 or 7 chains it is flatter, and then again much flatter. The abrupt face is probably the result of the ebb-tide acting tangentially in paring off the face of the bank; while at the other parts it comes upon the sand more in front, thus causing the bank to be more like a beach. The face opposed to the ocean is naturally flat. Before works were commenced, the ocean was labouring to build up the sand all along the bank; but within a short distance of Taiaroa Head, the most powerful part of the ebb was cutting off and transporting the sand brought from the outside, and whenever its carrying power was lessened by the joint opposition of the waves, and of the ebb tide coming down the coast, the solids would be precipitated. Hence the higher and wider condition of the bank at the northern part. During flood-tide, also, with a disturbed ocean, quantities of sand would be brought into the harbour, some of which would permanently lodge; but much of it would be picked up by the ebb and deposited on that northern area, which had fluctuations in depth like other parts of the bar, and when it was at its shallowest the channel in the line of beacons was at its best. This action of the ebb sufficiently accounts for the extension of the bank, and the accumulations in the north channel between the years 1850 and 1879, for the resultant of the inward wave force and the ebb current, would have an inclination northwards and shorewards.

To ascertain the nature of the bar, thirty-six probings were executed within 70 chains of Taiaroa Head in sixty-five hours' work, the larger number of tests being in the neighbourhood of the proposed channel and wall, being effected by a 3-inch tube, down which water was forced by the feed-pump of the hopper dredger. The deepest sinking was 44 feet, and the least 30 feet below low-water, giving depths into the bank of from 7 to 21 feet. These tests showed that the body of the bank was sand, with little variation, though the topmost 3 or 4 feet are less firm than below. The flat also to the south proved to be of similar composition.

In 1880 the Harbour Board contracted with Messrs. Simons and Co.[1] for the construction of a hopper dredger, which arrived in the colony early in 1882.[2]

Dredging, 1882–84.—The result of dredging on the bar, before the commencement of the training wall, was not satisfactory. In 1882 the dredger lifted 7,080 cubic yards of stuff in eighteen operations, and deposited it 3 miles out at sea, being an average load of only 393 cubic yards. An increase in depth of 2½ feet was gained for a short time; but, as there was no indication of permanency, the Author again urged the adoption of other means for the attainment of better depths on the bar. In 1883 the dredger removed 34,017 cubic yards in fifty-nine operations, or an average of 576 per trip, being a little over two-thirds of her full complement. In October, however, 11,650 cubic yards were removed in fifteen days' work, or an average of 777 cubic yards per day. During that steady work the low-water depth in a narrow trench was nearly 21 feet; but the return of less favourable weather, and the consequent stoppage of dredging, was immediately followed by a reduction in the depth to 18¼ feet. In 1884 the dredger was thirty-three times on the bar, and removed 21,585 cubic yards, or an average of 654 per trip. Still, no greater depth than 18¼ feet could be depended upon.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 40.

[2] Hull of iron, 210 feet long and 41 feet beam. Ladder, 76 feet long with thirty-six buckets; one set of 8 and the other of 10 cubic feet. General speed in working, fourteen buckets per minute. Hopper capacity, 850 cubic yards. Loaded draught, 10½ feet forward, and 14½ feet aft. Twin screws, and two pairs of compound engines, with cylinders 22 and 39 inches diameter. Two tubular boilers with working strength of 60 lbs. per square inch. When dredging, one pair of engines, with 50 to 55 revolutions per minute, was sufficient, but when in motion, both engines were used, consuming 5 cwt. and 15 cwt. of coal respectively per hour. The coal was obtained from the west coast of the Middle Island, where there are immense deposits of a bituminous character, with about 7½ lbs. evaporative power. The dredger was provided with heavy harrows, but neither in the upper harbour, nor on the bar, were they efficient, as there was no strong current to carry away the sand when it stirred up. In November 1884 one of the cast-steel bucket-backs broke during work on the bar, and the whole chain of buckets slipped from the ladder and sank. When recovered after a few days, the accident was found to be due to air-blows in the metal. In the following year, they were replaced by malleable iron ones, at a cost of £909. In January 1887 the dredger sank after collision with a steamer at the islands, but was speedily recovered, and repaired at a cost of £1,626 6*s*. 10*d*.

Training Wall.—The Board having become convinced that other means than dredging must be resorted to, the Author, early in 1883, prepared designs for the construction of the Western Mole, on the line recommended by Sir John Coode, which were duly approved by the Colonial Marine Engineer. Before being sanctioned by the Governor in Council, they were submitted to Sir John Coode for his opinion, especially as to whether the execution of the portion within the capacities of the Board's funds would be likely in any degree to operate against the success of his complete design, if at any future time it could be carried out. That scheme provided for two walls, the western one starting from the land, and extending into 28 feet depth at low-water on the outer slope of the bar, with a length of 6,200 feet; and the eastern one, 1,700 feet long, commencing at the extreme point of Taiaroa Head (Plate 2, Fig. 2). He replied that the western wall should not be extended further than 4,000 feet, unless the eastern one was also gone on with, and that though a certain amount of fluctuation in the depths on the bar would still be experienced, the degree of improvement obtained from this portion of the work would be worth the expenditure incurred.

A good supply of stone, suitable for a wall of random work, being available within ½ mile of the root of the proposed work, the Author proposed that method of construction (Plate 2, Figs. 5 and 6). The cliffs, 300 feet in height, consist mostly of a hard basalt, but partly also of a volcanic breccia, lighter than the basalt, but capable of easy quarrying in large blocks. There was also a heavy and extremely hard variety of rock at the northern end, which was used, to a limited extent, towards the end of the work; but it was costly to work on account of the extreme difficulty in drilling. There was a considerable falling off in the quantity of 6 to 8-ton blocks, at a time when an endeavour was being made to raise the work above low-water, where the wave force was particularly severe, and consequently a large quantity of the rubble was carried to leeward, unnecessarily spreading out the width of the wall.

In the absence of suitable hard wood in the colony, piles of iron bark,[1] red gum, blue gum, and turpentine, from Australia, in obtained for the staging for constructing the mole.[1] For the superstructure, native timber alone was employed. On the first section, 524 feet in length, black pine (*podocarpus spicata*) was used,[2] but thereafter a red pine was substituted, for economical reasons, and it was also found to have the advantage of giving a better grip for the feet of the workmen. The distance between the piles longitudinally was made 22 feet, as timber beams strong enough for that span could be got in the colony, whilst a larger span would have required costly under-bracing of iron (Plate 2, Fig. 5). Six longitudinal beams carried three lines of rails, from each of which stone was tipped as required. The piles sank about ¼ inch per blow of a 30-cwt. monkey with an 8 or 10-feet fall. They were driven 12 to 18 feet into the ground, the greater depth being in the seaward portion. Vertical wrought-iron bracing was placed at the piers, and was moved forward as soon as enough stone was placed to secure the piles. In accordance with Sir John Coode's recommendation, the rails were placed 18 feet above high-water; but as there was a tendency to fall going seawards, the outer two-thirds of the lengths were built with a rise of 0·15 foot per 100 feet, which raised the rails 22 feet above high-water at the outer extremity, a height not at all too great as experience proved. Three feet above low-water was the limit of height first proposed for the rubble; but Sir John Coode recommended high-water as the level for the first 500 yards, and 2 feet lower, or 4½ feet above low-water, for the remainder. Only a part of the inner end is up to the proper height, and the remainder falls short of even the lowest limit proposed (Plate 2, Fig. 6). The higher part at the beach end, by impeding the sand in its course from the westward, has fulfilled the purpose intended.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 313.

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[1] As the structure was only required for the deposit and consolidation of the rubble, the employment of jarrah from West Australia was not considered, as its cost is much greater than that of these other timbers; but, apart from this, the Author can endorse the statement of Mr. Ohaimer, that in several cases its use has been a disappointment on account of its yielding within a few years to the attack of the teredo. Such experiences are not uncommon in the colony with timber of good repute, probably in many cases caused by differences in the locality of growth, but often it may be suspected from mistakes in the names of the timbers, for some of very similar appearances have quite different characteristics. In the matter of durability in either air, earth, or water, few colonial timbers can excel the heartwood of New Zealand totara (*podocarpus totara*); but it is deficient in strength, and decidedly brittle when large and old.

[2] This wood is slightly stronger than oak, but is sometimes uncertain, owing to coarseness of grain. The heartwood has often shown great lasting qualities; but there is a danger of a timber of less durability, and very similar in appearance when sawn up, called miro (*podocarpus ferruginea*), being taken instead. The red pine is rather weaker.

Contracts were obtained for the supply of piles, squared timber, malleable and cast-iron, and workmanship of the staging; and the quarrying, the carriage, and the deposit of the stone were effected by day labour. By this means everything was got at about its first cost; and as the Board accepted the responsibilty for the stability of the structure as soon as the stone wagons were run upon it, and as these followed close upon the piles, the contractors' risk was very small. Had the whole been put in one contract, the item for risk and probable losses would have been very high; but these did not cost the Board over £100.

The average cost of the staging, exclusive of maintenance, light at the outer extremity, and a few minor items, was as follows:—

	£	*s.*	*d.*	
1st section, 524 feet	8	3	6	per lineal foot
2nd „ 506 „	7	18	6	„ „
3rd „ 990 „	7	14	10	„ „
4th „ 990 „	7	9	6	„ „
5th „ 1,078 „	7	1	1	„ „

The reduction in rate, as the structure extended from the beach, was partly due to the cheaper labour and material, consequent upon the relaxation of Government works, and partly to increased familiarity with the operations, and the freedom from serious accidents in the earlier part of the undertaking. The handling of the stone by the Board's own workmen, secured perfect control by the engineer over the sizes and qualities of the material put into the work. For about half the time, one of the quarries was worked by prison labour, the cost of which, compared with free labour, was slightly in favour of the former. The convicts cost the Board 3*s.* a day, made up of 2*s.* 6*d.* paid to the Government, and 6*d.* per man as the cost of carrying them and their stores between Dunedin and the works. The free labourers were paid 7*s.* per day of eight hours. Disadvantages in the employment of prisoners were their fluctuating numbers, and the inexperience of many of them.

The total quantity of stone put into the wall, between January 1885 and November 1888, when the work was stopped owing to the failure of funds, was 283,341 cubic yards; and the cost, including the formation of railways from the quarry to the mole, and to the landing place, was £35,831 3*s.* 2*d.*, or 2*s.* 6¼*d.* per cubic yard. The railways, however, are included, which are available for future use, either in maintenance or extension. The actual working expenses were 1*s.* 11*d.* per cubic yard in 1885, when the stone was easily got, up to 2*s.* 4*d.* in 1888, when circumstances were not so favourable. Up to the stoppage of the work, in November 1888, the cost had been :—

	£	s.	d.		£	s.	d.	
Staging	31,272	7	0	=	7	13	0	per lineal foot
Mole and railways . .	35,831	3	2	=	8	15	0	„ „
Total	67,103	10	2	=	16	8	0	„ „

Adding £1,836 6*s.* 3*d.* as the cost of 18,513 cubic yards of stone deposited in 1890, the cost of the wall amounts to £37,667 9*s.* 5*d.*, or £9 3*s.* 9*d.* per lineal foot; and the total expenditure upon staging and wall has been £68,939 16*s.* 5*d.*, or £16 16*s.* 3*d.* per lineal foot (see Appendix). In an estimate put before the Board by the Author, in June 1883, for the larger wall, the average rate was £16 18*s.* 10*d.* per lineal foot. The rubble is higher at some parts, and lower at others, than was at first proposed; and the staging is wholly higher, so that the actual cost was very close to the estimate.

The Table on the next page shows some of the principal points regarding the improvement of the bar, and the results produced.

From May 1882 to November 1887, the dredger, operating on the bar 186 times, carried away 108,994 cubic yards, or an average of 586 per trip, equal to 0·69 of her hopper capacity, the short filling being due in most cases to an increase of the wave-motion before her full complement was dredged. She worked bow on to the sea, with only bow and stern moorings, because side ones would have been too great an obstacle in the way of vessels. She was, therefore, very unsteady, but with the short seas from the north, she could work with waves 4 to 6 feet high; whereas with the long swell from the south-east, the motion became too great with waves half that height. Her ladder is of the box-girder pattern, very buoyant, offering a large surface to the sea, so that its heavy surging caused much damage to the buckets by their knocking against the bottom and sides of the cut. The large buckets proved unsuitable for this work, so that the smaller ones had to be used; and as it was impossible to shift them each time she changed her locality, the work done in smooth water was less than it otherwise would have been. Within the same period, the dredger removed 763,904 cubic yards from Port Chalmers and the upper harbour; so that of her whole dredging, only 12·4 per cent. was that for

Operations and Alterations on Otago Bar, May 1882 to April 1891.

Period.	Dredging Occasions.	Dredging.	Navigation Channel.		Length of Staging at End of Period.	Stone deposited in Mole.	Breadth of Bar at 26 Feet below Low-Water.	Amount of Bar above 26 Feet below Low-Water for Length of 2,100 Feet.	Travel of Ridge seawards since January 1883.	Travel of Centre of 26 Feet below Low-Water Contours seawards since January 1883.	Average Low-Water on Ridge of Bar, for Length of 2,100 Feet.
			Variations in Low-Water Depths.	Low-Water Depth at End of Period.							
	No.	Cub. Yds.	Ft. Ins. Ft. Ins.	Feet Inches.	Feet.	Cub. Yds.	Feet.	Cub. Yds.	Feet.	Feet.	Feet. Ins.
1882 May to 31 Dec.[1]	18	7,080	16 6 to 19 6	19 0 Temporary	..	..	920	636,300	..	..	14 5
1883 1 Jan. to 31 Dec.	59	34,017	19 0 „ 21 0	18 3							
1884 „ „[2]	33	21,585	18 3 „ 19 6	18 3	400						
1885 „ „	42	27,080	18 3 „ 20 3	20 3	1,420	42,828	990	..	60	90	16 10
1886 September	..	..	..	..	..	..	..	..	630	410	
1886 1 Jan. to 31 Dec.	8	4,806	21 3 to 19 3	19 6	3,022	74,830	990	..	860	520	16 10
1887 „ „	28	14,426	19 3 „ 22 1	22 1	4,088	102,740	750	..	560	560	18 3
1888 1 Jan. to Nov.[3]	..	..	21 6 „ 23 9	23 1	4,088	62,943	620	151,750	1,020	590	21 0
Nov. 1888 to April 1891	..	..	23 0 „ 25 2	25 2	4,088	18,513	A narrow gut with 26ft. 2ins.	134,980	730	820	22 7
May 1882 to April 1891	188[4]	108,991	16 6 „ 25 2	25 2	4,088	301,854	920 to 620	636,300 to 134,985	..	..	14 5 to 22 7

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[1] The breadth of bar is taken at right angles to its length.

[2] The length of bar (2,100 feet) on which the average depths and cubic contents are taken, excludes about 300 feet next Taiaroa Head, which is subject to frequent changes independent of those affecting the main bank.

[3] Bar flat on top.

[4] Two occasions removing moorings.

the bar, a suction dredger would have been better; but as a large quantity of the material inside the heads was clay, the bucket type was the more suitable (see Appendix). The performances inside the harbour contrasted favourably with the effects on the bar; and if she had never lifted a yard of sand from the latter place, the results would have been quite as favourable. The condemnation of the dredgers for bar work would apply equally to all operations which did not include works for the training of the currents, for it was quite impossible to secure permanent improvement of such a sand bar without some alterations in the natural conditions. The dredger was excellent in design and workmanship; and since the suspension of her work in Otago Harbour, she has done good service in Melbourne, and is now doing equally well in Lyttelton Harbour.

The average interest and depreciation on the hopper dredger, from May, 1882, to the end of 1887, amounted to 9½*d.* per cubic yard, so that the whole chargeable against the bar for dredging is:—

	£	*s.*	*d.*
Working expenses	5,294	7	0
Interest and depreciation	4,314	0	0
Total	9,608	7	0

Accordingly, the slight temporary advantage gained in the three years, before the wall had made much progress, had cost about one-seventh of the expenditure on that permanent improvement. The rate for the bar has been taken the same as for the work at other parts, because, though the distance run was much less, the losses by damage to the plant, and incidental to the difficulty of work in that exposure, were much more than in smooth water.

Between January, 1883, and April, 1891, the low-water depth over the bar, in the line of navigation, has been increased from 16½ to 25⅙ feet. Though the dredging of 62,600 cubic yards, up to the commencement of the mole at the end of 1884, had practically made no difference in the permanent depth, there was a gain of 2 feet on the removal of 27,080 cubic yards of sand in 1885, the year closing with 20½ feet. This, indeed, shoaled to 19¼ feet under the influence of the heavy storms of August-September, 1886, but as soon as these had subsided, the deepening recommenced under the influence of the tide alone. Moreover, whereas under natural conditions, the bar was occasionally unfit for the passage of vessels of 18½ to 19 feet draught, there is now 30½ to 31½ feet depth at high-water, giving, except under circumstances of special severity, facility for the passage of vessels of the heaviest draught. Unfortunately the condition of the channel near Kaik jetty, and also a small length near Port Chalmers, limit the capacity of the whole harbour, but these places being in smooth water, their improvement can be accomplished with a moderate expenditure. The breadth of the bar at the navigation channel, in a direction at right angles to its length, and at 26 feet below low-water, is less by 300 feet than in its original condition. The section given for 1891 is rather misleading in this respect, owing to the manner in which the line of the beacons passes along, instead of across this particular part of the bar in its new position. The reduction of the bar above a 26-feet low-water line, and for a length of 2,100 feet, represents the scouring away of at least 500,000 cubic yards; and considering the frequency with which the bank would be made up by storms, the material shifted by the currents must have been enormously greater. The crest of the bar in the navigation channel is 730 feet further seaward, and the centre of the 26-feet depth has shifted 820 feet in the same direction. The two columns of figures in the Table (p. 318) concerning the motion of the ridge and contours must be considered in relation to each other; and it must be borne in mind that the fluctuations outwards and inwards of the ridge are due to the extreme sensitiveness of the upper layers of sand, which are thus readily affected by even moderate currents or wave disturbances; but, on the other hand, the motion of the central point of the 26-feet depth is more nearly representative of the behaviour of the body of the bank, and has shown a fairly steady progression seaward in about six years.

The great alteration in the contour lines between 1883 and 1891, are shown on Plate 2, Fig. 7; and the manner in which the 26-feet contours are tending, indicates that a channel has been formed along the line of strongest ebb, different in direction from the original North Channel, but evidently taking its form from causes similar to those which developed the older course, though acting upon a line trending more seawards. Practically the bank has kept its position close to Taiaroa Head, while the more northerly point has wheeled round so as to present a face directly opposed to the south-east seas.

Between 1883 and April, 1891, there was a large extent of scour north-west of the line of wall. Some of this was caused by the ebb rushing past the toe of the rubble as it advanced, and some of if the wall had been raised to the proposed height, the more recent portion of the scour north-west of the wall would have been less, while the action near its line, and between that and Taiaroa Head, would have been greater. The deposit outside the position of the old bar is the natural result of the strengthened ebb in arresting the sand from the ocean further seaward than formerly; while the deposit inside has resulted from the settlement of the solid matter brought in by the flood-tide, so soon as it got into a position of less agitation, and of weakened current in the wide basin just inside the entrance.

The depths on the bar keep very steady. Nevertheless, it is evident, from the two clearly defined lines of deep water, that the strongest parts of the ebb and the flood streams are not yet forced into the same channel. So long as this is the case, the entrance to the port cannot be considered to be in such good condition as is desirable in a harbour intended for the accommodation of the large trading vessels of the present day.

Such is the history of the entrance to Otago Harbour, and it may be useful in showing certain points bearing upon the formation of bars which have been built up by the action of the ocean and tidal water alone, with no fresh-water stream of consequence, and no contribution of solid matter from the land. The comparison between the results of dredging and of the training wall, in clearing away the obstruction to navigation, will demonstrate the vast advantage of permanent works and induced scour over the merely temporary expedient of dredging.

APPENDIX.

RATES OF MATERIAL AND LABOUR FOR THE IMPROVEMENT OF OTAGO HARBOUR ENTRANCE.

Labourers	7*s.* to 8*s.* per day.
Piles delivered at landing place	3*s.* 5½*d.* to 3*s.* 10*d.* per lineal foot.
Square timber delivered at landing place—	
Black pine	14*s.* to 17*s.* per 100 superficial feet.
Red pine	7*s.* 8¾*d.* to 10*s.* 3*d.* per 100 superficial feet.
Malleable iron	2⅛*d.* to 2¼*d.* per lb.

Work on Staging.

Piles—shoeing and placing ready for driving	4*s.* to 25*s.* each.
„ driving, per foot in the ground	1*s.* 11*d.* to 5*s.*
Square timber, per 100 superficial feet	7*s.* to 18*s.*
Foot planks „ „ „	4*s.*
Coal for dredging, 1885	26*s.* 3*d.* per ton.
„ „ „ 1886	23*s.* 5*d.* „

COMPARISON OF EXPENSES OF HOPPER AND STATIONARY DREDGERS.

Comparing the work of the hopper dredger and that of a stationary dredger, with its attendant steamers, barges, and cranes, the following figures are arrived at. The stationary dredger selected is the "Vulcan," with double ladder, of good design and make, and the year is 1885, when both dredgers had a good record of work.

"*Vulcan*" *Stationary Dredger, with Steamers, Barges, and Cranes on shore for Discharging.*

	Per Cubic Yard.	
	s.	*d.*
Working expenses, 247,608 cubic yards (material carried about 2 miles), £15,088 16*s.* 11*d.*	1	2·64
Interest and depreciation, 12 per cent. on the dredger, steamers, and cranes, and 15 per cent. on the timber barges. Total capital value, £45,451	0	5·00
Total	1	7·64

Hopper Dredger.

Working expenses in raising, carrying, and depositing—

	Cubic Yards.			Miles.		Per Cubic Yard. s.	d.
Bar	27,080	.	Double journey .	6			
Port Chalmers .	55,486	.	„ „ .	19			
North Harbour .	123,849	.	„ „ .	26			
	206,415	=	£6,809 15 7	=		0	8·00

Interest and depreciation—

12 per cent. on £44,290	=	£5,314 16 0	=	0	6·12
Total				1	2·12

So that the figures are in favour of the hopper dredger by 5½*d.* per cubic yard.

(*Students' Paper, No. 304.*)

"The Manufacture of Oil-Gas at the Holloway Works of the Great Northern Railway Company."[1]

By JAMES BENJAMIN BALL, Stud. Inst. C.E.

THE manufacture of oil-gas, and its application to lighting purposes, have already been described in Papers by Messrs. Arthur Ayres, M. Inst. C.E.,[2] and Gilbert Macintyre Hunter, Assoc. M. Inst. C.E.[3] It is the Author's intention to confine this Paper to a description of the plant used in the manufacture of oil-gas at the Holloway works of the Great Northern Railway Company. The Company also manufactures oil-gas at Doncaster and at Leeds, but on a smaller scale.

The Holloway works consist of an oblong range of buildings, about 278 feet in length (Plate 3). The boiler-house, 41 feet 6 inches long by 39 feet wide, occupies the centre; on each side of this extends an engine-house, 25 feet by 28 feet; a retort-house, 57 feet by 28 feet; and a purifying-house, 24 feet by 28 feet. On the south side, between the engine- and boiler-houses, are the workmen's mess-room and workshop, 15 feet by 28 feet. The boiler-house is 23 feet in height from the floor to the springing of the roof, the other buildings being 16 feet in height. The roofs are formed of wrought-iron bowstring principals, 8 feet apart, covered with galvanized corrugated-iron, the boiler- and retort-houses having ventilation in the roof. At the north and south ends of the buildings respectively are small counterpoised gas-holders, each 20 feet in diameter and 4,000 feet capacity, set in cast-iron tanks. On the west side are two sets of tar-tanks, each consisting of three galvanized-iron tanks set in brick and concrete pits built in the ground and covered with Yorkshire flags. On the east side extends a wooden shed 150 feet in length and by 25 feet; in which are placed six large galvanized-iron tanks, having a total capacity of 6,000 gallons; also the chamber for the steel compressed-gas holders 42 feet by 25 feet; the remainder being used for storage of fuel, duplicate plant, &c.

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[1] This communication was read and discussed at a meeting of Students on the 11th of March, 1892, and has been awarded a Miller Prize, Session 1891–92.

[2] Minutes of Proceedings Inst. C.E., vol. xciii. p. 298 *et seq.*

[3] *Ibid.*, vol. xcv. p. 218 *et seq.*

Pintsch's system of gas-making is employed, and the works have been designed to produce about 60,000 cubic feet of gas per day. At present, the average quantity of gas made is only between 15,000 and 18,000 cubic feet per day, owing to the fact that all the Company's carriages are not yet fitted to use the gas.

RETORTS.

In each retort-house, contained in four benches, are eight pairs of 10-inch D-shaped retorts, 6 feet in length, made of 1-inch metal. The pairs of retorts are placed vertically over one another, and are connected by cast-iron mouth-pieces on the opposite ends to those at which the oil is delivered; doors being provided in the mouth-pieces for cleansing purposes. In each upper retort is placed a small sheet-iron tray about 2½ inches deep. This tray becomes coated with carbon after a short time, and is changed and cleansed once a week, and renewed after about three months' use. Stouter trays made of steel are now being tried, and promise to prove much more durable.

The gaseous vapour generated in the upper retort passes down through the mouth-piece into the lower one, and escapes at the other end through a short vertical pipe into the hydraulic main. The retorts are set in specially-made fire-clay blocks, and on both sides small sight-holes are formed at the furnace end, with the object of ascertaining and regulating the temperature. They are kept as nearly as possible at a cherry-red heat; but the lower one, being immediately over the furnace, is generally at a higher temperature than the upper one; and this extra heat is beneficial in thoroughly gasifying the vapour before it passes into the hydraulic main. Each pair of retorts will make between 600,000 and 700,000 cubic feet of gas before they require to be taken out and renewed, the old retorts being broken up and partly used again for new castings.

At the bottom of the lower retort, immediately before the gas enters the hydraulic main, is a ¾-inch iron pipe tapped into the retort and provided with a stop-cock, by means of which the colour of the gas may be seen, this being the practical test applied to ascertain its quality, and whether the proper quantity of oil is being admitted into the retorts. Another test for regulating the supply of oil is to drop a small quantity of the tar from the gas-main upon a sheet of white paper. Should too much oil be admitted to the retort a greasy ring will be found around the spot of tar. If the right quantity is being used no greasy ring will appear. Below the stop-cock and tapped into the $\frac{3}{4}$-inch pipe, is a $\frac{1}{4}$-inch pipe which is carried to the wall of the building and attached to an ordinary water-gauge which registers up to a head of 12 inches. Each pair of retorts is provided with a separate gauge, and the working head, which is usually about $3\frac{1}{2}$ inches in the retorts, can be thereby observed. The furnaces are situated immediately under the retorts, the bottoms being formed by three $1\frac{1}{2}$-inch round cast-iron fire-bars 3 feet in length, resting upon three cast-iron cross-bearers. This arrangement permits the fires to be easily cleansed from clinker and ash, and the fire-bars to be renewed without trouble. Immediately below the fire-bars is an ash-pan which is kept full of cold water. The furnaces are arched over with fire-clay blocks, upon the flat crown of which the lower retort is seated. Three 4-inch by 3-inch openings or flues are formed in this arch on each side of the retorts, which are protected by a thin lining of fire-brick to a height of 5 inches. A clear space of 2 inches is left between the crown of the lower retort and the bottom of the upper one, which is thus fully exposed to the heat and smoke ascending from the furnace. Two small flues are formed on each side of the upper retort, and a semi-circular arch is turned over it 2 inches clear of the crown. In the centre of this arch an opening 10 inches square communicates with a semi-circular chamber extending the full length of the retort; and flues are brought over from all of these chambers into a centre shaft 9 inches square inside and carried up through the roof. The whole structure of the setting is held together by angle-bars at the corners with through-bolts. Notwithstanding this, it becomes more or less cracked after a little use, for the working of the retorts produces an expansion of $1\frac{1}{4}$ inch at each end.

When in proper working order, each pair of retorts produces on an average between 300 and 400 cubic feet of gas per hour, and the furnaces consume between 160 lbs. and 180 lbs. of coke for every 1,000 cubic feet of gas produced. The setting to the retorts is arranged so that a minimum of work in pulling down and rebuilding is required when new retorts are inserted. In working, is caused to fall upon the loose tray, placed in the upper retort, when it is instantly converted into a dense brown smoke; it then passes through the mouth-piece into the lower retort, from which it escapes through the hydraulic main into the condensers, purifiers and washers, respectively. Thence it passes through the meters into the gas-holders by a 6-inch iron main.

From the gas-holders it is conveyed by a 4-inch cast-iron main to the compressor-pumps, which force it through a 1-inch composition pipe into the steel store-holders, at a pressure of 10 atmospheres; and from these store-holders the receivers, which are placed under the bottoms of the carriages, are charged. The oil used is a once-refined shale-oil, and gravitates to the retorts from a galvanized-iron cistern of 50 gallons capacity, through a 1-inch iron pipe. At the end of the pipe is fixed a gun-metal micrometer cock, by which the oil flowing into the retort can be regulated to a nicety. From this supply-pipe the oil flows into a small funnel attached to a ¾-inch siphon-pipe 12 inches deep, which is connected to the upper retort.

HYDRAULIC MAIN.

At the back of the mouth-piece on each lower retort a cup is formed, and from this cup a 4-inch iron pipe with ball-shaped ends leads into a cast-iron box, 22 inches long by 11 inches deep, in the course of which another cup is formed to take the ball-shaped end of the pipe. Inside the box are formed two chambers, the larger one being filled with water. The pipe delivers the gas 1½ inch below the level of the water, when it is collected in the smaller chamber and thence passes into the gas-main. By this arrangement of ball-and-socket joint, provision is made for the expansion of the retorts, the joints being packed with a mixture of asbestos and plumbago. On the top of the hydraulic-box is a 3-inch hole provided with a wooden plug, by means of which fresh water is let into the box, the fouled water being drawn from the bottom; each box when in use is cleansed and refilled once a day. Every pair of benches of retorts is provided with a separate 6-inch gas-main and inspection-boxes, connected to a tar-box 22 inches by 11 inches. From these boxes a 1-inch siphon 8 inches deep delivers the tar into the tar-pit which is connected with the tar-tanks by a 2-inch iron pipe. Stop-cocks are provided immediately in front of the tar-boxes, so that each main may be shut off when not in use. A ¼-inch iron pipe is tapped into the side of the tar-box and led to the wall of the building, where it is connected to a water-pressure gauge similar to those provided for the retorts. The usual working-head of the gas-main when it is clean is 3½ inches of water. The mains are laid with a fall towards the tar-boxes of about 1 in 20.

CONDENSERS.

These consist of plain wrought-iron vertical cylinders, 30 inches in diameter and 8 feet in height, connected together at the top; one pair of condensers being provided for every two benches of retorts. After leaving the tar-boxes, the gas enters the bottom of one of the condensers and, rising to the top, flows down through the other and escapes from the bottom into a 6-inch main leading to the washers. At the foot of each condenser a 1-inch siphon 8 inches deep is provided for drawing off the tar, and is connected to the tar-tanks.

WASHERS.

The washers consist of circular iron boxes 3 feet 6 inches in diameter and 3 feet deep. In each box is a sheet-iron tray, in the centre of which is formed a cylindrical chamber 9 inches in diameter and 9 inches deep. The gas from the condensers is led by a pipe through the bottom of the washers into this chamber. Upon the under side of the tray spreaders are fixed, to cause the gas to be driven under the water, whence it finally escapes through small holes at the sides of the tray into the outlet-pipe leading into the purifiers. The tray has a water-seal of about 1½ inch. Siphons are fixed at the bottoms of the washers for drawing off the tar.

PURIFIERS.

Two purifiers are provided for every two benches of retorts, and these are arranged so that, by means of a four-way valve placed between them, the gas can be turned from one to the other, or made to pass through both. They consist of wrought-iron boxes 3 feet 6 inches by 4 feet 6 inches by 2 feet 6 inches deep, provided with wicker trays upon which lies a 2-inch layer of slaked lime and sawdust, in the ratio of two parts of lime to one part of sawdust. These trays are taken out, cleansed, and provided with a fresh layer of lime and sawdust every week, and last about eighteen months. The working-head varies from 1¾ inch to 2 inches of water.

Meters and Gas-holders.

After leaving the purifiers, the gas passes through the wet meters, which are 3 feet 6 inches in diameter, and capable of passing 1,500 cubic feet of gas per hour. They are provided with by-passes, so that the meters may be taken down and repaired if necessary, without interfering with the working of the retorts. Two meters are provided in each retort-house, and may be worked either together or separately. From the meters, the gas is led into the gas-holders, which are 20 feet in diameter, built of No. 15 B. W. G. iron sheets, the roof being formed of No. 14 B. W. G. sheets. They are set in cast-iron tanks of ¾-inch metal, 12 feet deep, formed in sections 4 feet by 4 feet, and bolted together, the joints being made with rust cement. The working head in the gas-holders is generally 1½ inch of water.

Compressing-Engines.

There are six compressing-engines arranged so as to be capable of working either singly or together. They are horizontal single-cylinder non-condensing engines with two heavy fly-wheels 6 feet in diameter. The compressor-cylinder is fixed in line with the steam-cylinder, the piston being worked by two cranks and connecting-rods fixed to the outsides of the fly-wheels, and connected to a double-slide pivoted in the centre at the end of the steam piston-rod. An eccentric on the main crank-shaft gives motion to the slide-valve by a lever-and-slot arrangement. The steam-cylinder is 10 inches in diameter with a 12-inch stroke; and, at 45 revolutions per minute, easily compresses 1,400 cubic feet of gas per hour.

The compressor-cylinder is 6⅝ inches in diameter, with a 12-inch stroke, and is water-jacketed; the water being constantly circulated whilst the engines are at work. In cold weather it is drawn off when the engines are at rest, by means of a cock in the cylinder. The gas is admitted at each end of the compressor-cylinder, with corresponding outlets of ½-inch pipe, which are brought together in the delivery-cylinder, and connected to the 1-inch main leading to the store-holders. The delivery-cylinder is charged with water, the waste-water from the compressor-cylinder being used for this purpose. The supply of gas to these engines is so arranged that it may be drawn from either or both of the gas-holders.

BOILERS.

There are three 25-HP. Cornish boilers 5 feet 6 inches in diameter, and 22 feet in length, with a 36-inch Adamson welded and flanged flue, made by Messrs. Tangye, of Birmingham, of best mild-steel plates. The boiler-plates are of $\frac{3}{8}$-inch Siemens-Martin steel, and the flue of $\frac{7}{16}$-inch "fire-box" quality. The boilers have been tested to 140 lbs. pressure per square inch. At present, however, only one boiler is used, and works at 60 lbs. per square inch. The feed is arranged for either injection or direct supply from the Water Company's main. The boilers are 8 feet 6 inches apart from centre to centre, and are set in brick-work upon a concrete bed 29 feet in length. The brick-work is carried up to within 15 inches of the crown of the boilers, and is covered with 3-inch York flags. The exposed portion of the boilers and all the steam-pipes are coated with patent non-conducting material. The flues are brought together and regulated by dampers at the chimney-shaft, which has a flue 3 feet 6 inches square at the foot, and is lined with fire-bricks to a height of 20 feet. The shaft has a square base 2½ bricks thick, carried up to a height of 20 feet; upon this a circular shaft is built in mortar, with a 42-inch flue at the base, tapering to 33 inches at the top. The bond is three courses of stretchers to one of headers, four courses being laid in cement instead of mortar at every 12 feet in height. The total height of the shaft is 80 feet, and the top is surmounted by a cast-iron cap weighing 16 cwts. The boilers consume between 75 and 85 lbs. of coke for every 1,000 feet of gas produced.

STEEL STORE-HOLDERS.

The gas is forced by the engines through a 1-inch extra-strong leaden pipe, which weighs 14 lbs. per yard, into fourteen cylindrical steel receivers, 4 feet 3 inches in diameter and 17 feet 6 inches in length; each of a capacity of 250 cubic feet, and having been tested by hydraulic pressure to 300 lbs. per square inch. Each holder is provided with a pressure-gauge registering to 200 lbs. per square inch, and special valves placed on the inlet-pipes prevent the pressure from coming back into the delivery-pipes. At the end of each holder is a man-hole, and provision is made for drawing the gas back into the gas-holders should it be found necessary to do so. A cock is placed at the bottom of each holder a fortnight and sent away, every 1,000 feet of compressed gas yielding about a gallon of hydro-carbon. Three holders are fixed at the Finsbury Park sidings, and connected with those at the works by a 1-inch lead pipe. Other holders will shortly be fixed at the Holloway sidings and at King's Cross.

From these holders, a 1-inch pipe is laid between the sidings, provided at intervals of 50 feet with gun-metal filling-cocks fixed in cast-iron filling-boxes with covers; and from these filling-cocks the cylinders under the coaches are charged, several 30-feet lengths of flexible hose being provided for this purpose. Nearly 8 miles of main have now been laid.

STORAGE OF OIL.

Six galvanized-iron tanks, each holding 1,000 gallons, are provided for the storage of oil, and a 1-inch main is led from these tanks to the small tanks which feed the retorts, the oil being pumped into the small tanks by rotary pumps. The oil is brought to the works in barrels and pumped into the large tanks, a gauge being provided to show when they are filled.

TAR-TANKS.

These are placed in a chamber formed in the ground; each set contains three galvanized-iron tanks, each tank being capable of holding 1,000 gallons. The tar is led into the two outer tanks and sinks to the bottom, leaving the water on the top. This is drained off into the centre tank, each side tank being connected to the centre one by a $\frac{3}{4}$-inch pipe situated 10 inches below the top. The two outer tanks thus contain the pure tar, whilst the centre one contains water with but a small admixture of tar. When the tar-tanks are full they are pumped out, and the tar is sold.

There are six men engaged at the works. The machinery, retorts, store-holders, &c., were supplied by Messrs. Pintsch and Co.; the buildings having been erected by Messrs. Atherton and Latta, of Poplar.

The cost of the works, including twelve steel store-holders, two gas-holders, eighteen filling-hoses, one hundred filling-boxes, and 3 miles of 1-inch heavy gas-main laid in wooden casing, with all connecting gun-metal joints, stop-valves, &c., was as follows :—

	£.
Buildings	6,626
Machinery, &c.	8,114
Total . . .	£14,740

The cost of the Doncaster installation, which is much smaller than that at Holloway, and consists of four benches of retorts, three sets of compressing-engines, one gas-holder, two 16-HP. boilers, fourteen store-holders, eighteen filling-hoses and one hundred boxes, with 3 miles of gas-main complete, was as follows :—

	£.
Buildings	3,958
Machinery, &c.	5,891
Total . . .	£9,849

The works have been designed by, and been carried out under the instructions of, Mr. Richard Johnson, M. Inst. C.E., Engineer-in-chief of the Great Northern Railway, to whom the Author is indebted for permission to furnish the information contained in this Paper, and to permit the reproduction of the drawings, from which Plate 3 has been prepared.

(*Students' Paper No. 301.*)

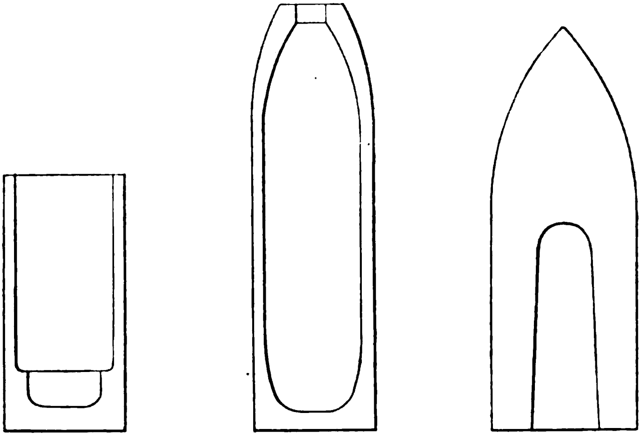
"The Manufacture of Forged-Steel Projectiles."[1]

By David Carnegie, Stud. Inst. C.E.

(*Abstract.*)

The use of forged steel for the manufacture of projectiles is chiefly due to its penetrating properties, and its adaptability for the construction of shells, which, when made of this material, afford considerable capacity for the charge with any given calibre, by reason of the thinness of their walls.[2] Projectiles may be classed as, (1) Armour-piercing projectiles; and (2) Hollow shells; both of which are illustrated in *Figs. 1.*

Figs. 1.



Shrapnel Shell. Common Shell. Armour-piercing Shell.

The Author's Paper is confined to a description of the methods employed in the manufacture of the second class of projectiles known chiefly as "common" and "shrapnel" shell. Reference is, however, made to a few processes in the manufacture of those of the first class.

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[1] This communication was read and discussed at a meeting of Students on the 29th of January, 1892, and has been awarded a Miller Prize, Session 1891–92.

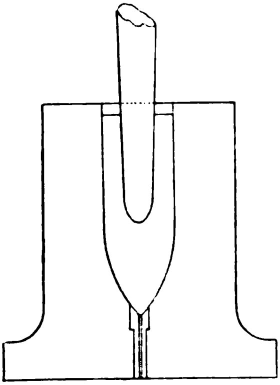
[2] Farrow's Military Encyclopædia, vol. ii. p. 591.

An important elementary consideration is the quality of the steel. Chemical analyses and mechanical tests are usually employed to ascertain this. Chemical analysis alone cannot be relied upon. Dr. W. Anderson says the reason why chemical analyses are not sufficient to decide the quality of the steel, lies in the circumstance—

> "That the mechanical properties of steel, and of alloys generally, are affected in a remarkable manner by extremely minute quantities of substances associated with the dominant metal, by the relative proportions of these substances, by the changes in some, or in all of them, produced by more or less rapid changes of temperature, which influence dissociation, and reveal their effects by the singular phenomenon known as recalescence, which also indicates, though to a less degree, allotropic change in some or all of the components."[1]

Even when recourse is had to mechanical tests, the result is sometimes misleading and unsatisfactory. It is often found that test-pieces taken from one bar a few feet in length give varying results; and the quality of steel with regard to ability to pierce hard-faced armour without fracture, and to resist the shock of discharge, is tested practically by firing a few projectiles made of that material, under conditions that exceed the requirements of ordinary practice.

Fig. 2.



Mould and Punch.

Armour-piercing projectiles are usually made from solid ingots of steel containing from 0·8 per cent. of carbon for the smaller sizes, to 0·7 per cent. of carbon for the larger sizes, with from 1 per cent. to 2 per cent. of chromium. The ingot is cast head downwards in a cylindrical metal mould, considerably larger in diameter than the required shell. The body of the ingot, after being re-heated, is drawn down by swages under the steam-hammer. The utmost care must be used in the re-heating and forging; the ingot, if over-heated, or unequally heated, may be rendered useless; and the harm done thereby may be only detected during the process of hardening, after a considerable amount of labour has been expended upon it. Several other plans have been tried to manufacture armour-piercing shot so as to have the required properties without the necessity of subsequent forging. One method consists of casting in a mould, as shown in *Fig. 2*, an ingot of steel; which, while in a molten condition, is subjected to considerable longitudinal pressure. After the casting has reached a semi-solid condition, the interior cavity is formed by a punch, which is forced into the material under hydraulic pressure, and instantly withdrawn. As a modification of the last method, it has been suggested that it might be advantageous to have a small hole in the bottom of the mould, the top being solid with the exception of a hole large enough to allow the punch to pass into the material. Instead of an upward flow being induced, the surplus metal would by this means be pressed out at the small hole in the bottom. There are, however, many practical difficulties in the way of a successful application of the last-mentioned process.

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[1] "On Tests for Steel used in the Manufacture of Artillery," *Engineering*, 15th May, 1891, p. 599

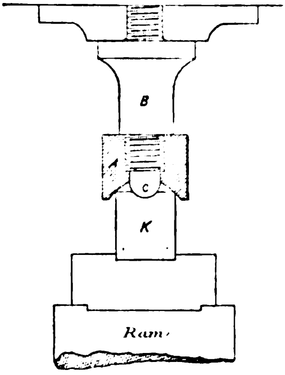
After casting and forging, the projectile is machine-turned all over, and the cavity is bored out to the required dimensions. The final operation is that of hardening the point. Up to this stage, a good deal of labour has been expended in the production of an article which not infrequently proves useless, owing to mishaps in tempering and hardening the points. These are largely due to the fact that the material, when so treated, is incapable of resisting the internal stresses set up during hardening, by the rapid cooling of the exterior, while the interior remains hot. It is not an uncommon thing for a projectile which has been successfully hardened and sent out by the manufacturer as satisfactory, to crack spontaneously at some subsequent time. This must be the result of continued internal stress. In connection with this matter, Dr. W. Anderson says, in the article quoted above:—

> "As there is no such thing as an absolute elastic limit, time, to some extent, obliterates the internal stresses; the metal slowly yields under them until a sort of armed neutrality is produced; so that, after a few months' repose, spontaneous fracture need hardly be dreaded; and for this reason dies and armour-piercing shot are kept in store for some time before being issued for service."

Another method of manufacture consists of electrically welding the head and base (previously forged) to the body, which is made from drawn-steel tubing. This method is said to have originated in America. Mr. Hadfield, in *Iron* of the 14th November, 1890, gives valuable information on this subject.

Several methods of manufacturing shells belonging to the second class have been tried, a few of which have proved successful, and are practised at the present time. Delmard early introduced the method of solid drawing, which consists of pressing, through suitable dies, a disk of hot steel, the thickness of which is a little greater than the wall of the shell required. In the centre of the disk the metal is usually thicker, for the purpose of forming the base or head of the shell, as the case may be. Another and more successful plan is that of welding wrought-iron bases into tubular steel. The tube is first made to the proper dimensions of the body of the shell, and is then cut off to the required length. One end of it is heated and up-set before the base is driven in. The welding is effected in a furnace that is constructed so as to concentrate a welding-heat round the end of the tube, while the rest of it remains comparatively cool. When the proper temperature has been reached, it is removed from the furnace and finished with suitable tools under the steam-hammer, and finally pressed through a ring-die. It is obvious that the success of this operation depends upon the production of a sound weld, which requires much practical skill on the part of the workmen. A practical and very efficient process is that pressing the shells out of short cylindrical pieces of steel into the form of cups, which are then gradually drawn into shell form. The following is the method usually adopted. The bars of round steel from which the shells are made, when received from the rolling-mill, have a diameter slightly larger than that of the required shell. The short cylinders of steel cut from the bars are heated in an ordinary re-heating-furnace. The fuel used is gas, generated from coal in a gas-producer. The furnaces are generally placed between the punching- and drawing-machines, and are provided with two lift-doors on each side, suitable for use at either end of the machines. When the pieces of steel have reached a temperature of about 900° C. (a white heat), they are removed one by one from the furnace with tongs, and are placed in a block which rests upon the ram of a vertical hydraulic-press. The centering of the steel blocks is completed in this press. This is done with a punch, which is fixed to the top frame of the press. As the ram ascends and approaches the punch, the steel block K, *Fig. 3*, is held in position by a guide A, which forms part of the punch B. The object of this operation is to make a small cavity C in the centre of the block. The steel is removed from the press to the furnace, and is again heated to the same temperature as before, after which it is removed and the oxide of iron is scraped off before

Fig. 3.

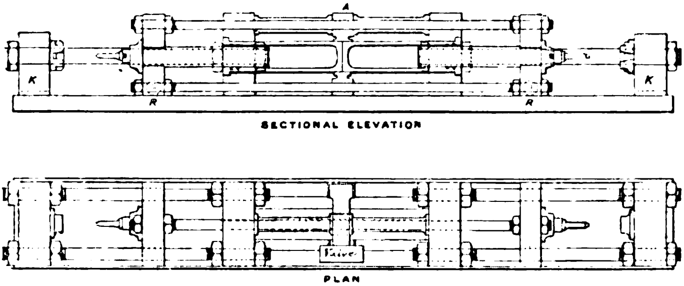


Steel Centering-Block.

the block is further treated. On each side of the furnace alluded to there is a large horizontal hydraulic-press, *Figs. 4.* One is used for "punching," whilst the other does the work of "drawing." Each press has two cylinders, with their closed ends butting against each other and supported in a central standard A, bolted to the bed-plate. The open ends of the cylinders are similarly supported. The rams are connected, so that any forward movement of one gives the reverse movement to the other. At the same time, the rams are supported and guided centrally by carriages which move along the bed-plate on rollers R R. To these carriages are fixed the blocks into which the punches are screwed. On the bed-plate, at the extreme ends, there are also bolted massive standards K K, to which are fastened the die-blocks. The usual pressure on the ram is about 1 ton per square inch.

Scaling has always been a source of inconvenience and trouble, as it must be removed previous to punching or drawing in every operation. The methods adopted for its removal have not proved very satisfactory. One way of removing the scale from the steel blocks is with hand-scrapers; and, as this must be done with as little loss of heat as possible, one man holds the hot steel with a pair of tongs, while three men clean it with long hand-scrapers. Another way is to suddenly plunge the hot steel into cold water, and to brush the oxide off the steel with a wire-brush. This method is, of course, only suitable when the scale is thin. Automatic gear has been designed for the purpose of at once removing the oxide and guiding the steel block into the die previous to punching. This arrangement, *Fig. 5*, consists of a bracket fixed to the face A of the die-block. On B is fitted a slide S which carries the scrapers and guide. The slide and scrapers are in position

Figs. 4.

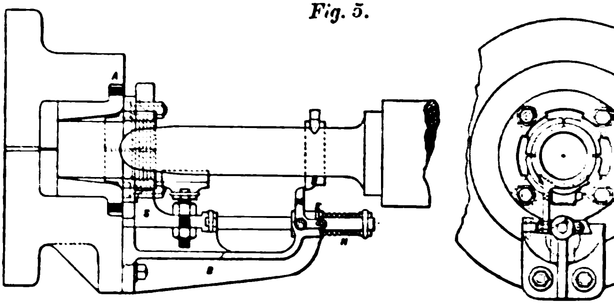


HYDRAULIC FORGING-PRESS.

pressure of a powerful spring N, by a small latch E, lifted when the projecting collar H on the punch, d forward movement, strikes the bell-crank lever M and rel spring. This takes place after the steel has been passed the scrapers into the die and the point of the punch ha the steel. The whole arrangement slides back under the of the spring on the bracket B, and thus makes room for t drawal of the punched steel.

The pressure employed to punch steel ingots, necessi use of specially good cast-steel punches. The larger cast in sand-moulds, and are turned without previous whilst the smaller sizes are made from rolled-steel, cont high percentage of carbon. The dies are generally made iron. It is important that the material of which they a should be of such a quality as to produce a glossy ski surface of the shell when finished. The materials wh

Fig. 5.



Sectional Elevation. End View.

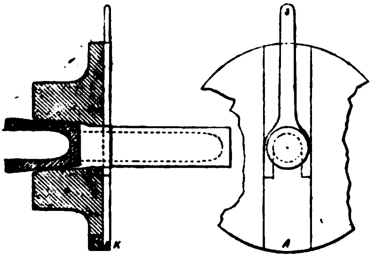
COMBINED SCRAPING AND CENTERING TOOL.

been tried for the purpose, are :—(1) Hard cast-iron; (2) cast-iron; (3) Cast and forged steel. Of these, the first m material has proved the most satisfactory. It is nece warm both the punch and the die previous to each operatio mash of black-lead is laid on both tools. Should the material fasten itself in the die, the application of a drift the gas-outlet in the bottom ensures its removal. Coal-du infrequently thrown into the bottom of the die previou introduction of the steel, should the washing with bl mixture be found insufficient for the formation of gas to buffer. Immediately on the withdrawal of the punch it i by water. This is indispensable, as otherwise it would

The second operation is conducted in a similar manner to the first, after the steel has been re-heated. The only difference is that the punch used in this case gives the interior of the shell its proper shape. In this operation, greater difficulties have to be overcome than might, at first sight, be imagined. For example, when the punch is withdrawn from the hot steel, an accumulation of scale, carried by the punch from the sides of the already formed cavity, is found pressed hard into the metal at the bottom. This scale can be easily knocked out when the shell is cold; and the consequence is, that an ugly irregular cavity is left. One way in which this difficulty is met, is by making the point of the punch slightly hollow to allow for the accumulation of scale.

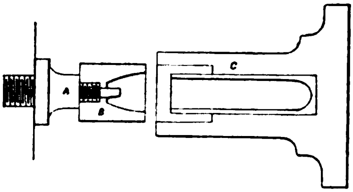
In the remaining operations, the partially finished shells are pressed through cylindrical cast-iron dies, each subsequent "draw" reducing the diameter of the shell. Ordinarily, two "draws" are sufficient, provided that the dies are properly shaped.

Fig. 6.



Drawing-Die.

Fig. 7.



Heading-Tool.

Fig. 6 represents an ordinary drawing-die, with shell and punch in position, previous to drawing. After the shell has been pressed through the die, it is removed from the punch during the return stroke, by means of a stripper S, made of hard steel in the shape of a pitch-fork. It passes over the punch, and fits into the slot A, between the back of the die-block and the standard K. The shells, when punched, have often a long side; they must in such cases be placed with the long side to the top or to the bottom of the die, so that the stripper may have an equal hold on both sides of the shell; otherwise the punch is unduly strained on one side, and the result may be serious. The formation of the heads of "common" shells is effected thus:—When the body of shell has been reduced to the proper diameter by drawing, it is removed to the lathe. The bottom is faced up and sufficient metal is cut from the open end to ensure the shell being of the required length when the head is formed on it by closing the open end with a tool, illustrated in *Fig. 7.*

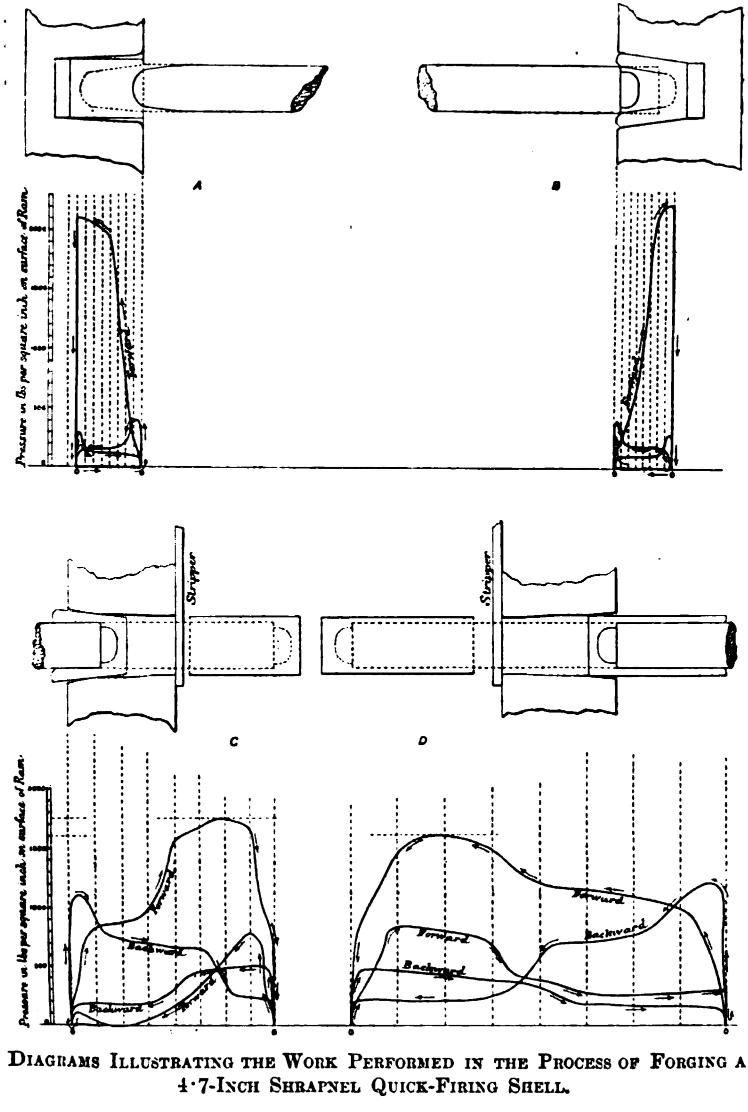
This tool is screwed into the punch-holder of the press. It consists of two parts, the mandril A and a steel cylinder B screwed on it; the latter is bored out to the shape of the head of the shell and fits into the cast-iron die shown at C. To close in the head, the shell is heated for a few inches from the open end, the remainder being kept cool. The open end is gradually closed in with the heading-tool. This is done in successive stages, three heats being usually required for the purpose. The fuse-hole in the point of the shell is formed by the metal closing round the point of the heading-tool C, which is tapered. Should the shell fasten itself on to the pin C, as often happens, the part B of the heading-tool is unscrewed, and the shell pressed off without much loss of time. This method of closing in the heads of "common" shell has proved successful.

The work done in forging, as described above, has been thus estimated :—

The diameter of each ram of the presses is 16 inches; the area of the same is 201·06 inches; and the average speed of the rams is 10 feet per minute. Pressure-gauges are connected to the pipes, through which the water is admitted into and exhausted from the cylinders alternately, and from these gauges the forward and backward pressures in the respective cylinders may be obtained at any position of the stroke while the rams are in motion. From their indications, and the speed of the rams, the Author has plotted out curves representing approximately the development of the pressure during each operation in the manufacture of a 4·7-inch Shrapnell shell for quick-firing guns. The diagrams A, B, C, D, *Figs. 8*, indicate respectively the first, second, third, and fourth operations. The curves projected below each figure are the result of several experiments, and are obtained from the position of the punches and the corresponding pressures, as indicated by the pressure-gauges. The work done in each operation is calculated from the diagrams thus plotted. The results of these calculations are as follows :—

Work done during the first operation, "Punching" = 65·9 foot-tons.
" " second " " = 55·9 "
" " third " "Drawing" = 309·1 "
" " fourth " " = 404·6 "

Figs. 8.


A
B
Pressure in lbs per square inch on surface of Ram
Forward
Stripper
Stripper
C
D
Pressure in lbs per square inch on surface of Ram
Forward
Backward
Backward
Forward
Forward
Backward
Backward
Forward

Diagrams Illustrating the Work Performed in the Process of Forging a 4·7-Inch Shrapnel Quick-Firing Shell.

The steel cylinder used for this particular shell is 4·75 inches in diameter and 5½ inches in length. The approximate weights before and after manufacture are 27 lbs. and 26½ lbs. respectively. The average loss of weight from scaling is, therefore, 1·85 per cent. per shell. In the process of manufacture, the energy expended depends largely, of course, on the temperature, the quality of the steel, and the amount of metal displaced.

The communication is illustrated by eight tracings, from which the *Figs.* in the text have been prepared.

(*Paper No. 2603.*)

"The Use of Sea-Water for Street-Watering, Sewer-Flushing, and the Other Purposes required by Sanitary Authorities."[1]

By JOHN WILLIAM COCKRILL, Assoc. M. Inst. C.E.

THE Author has had charge since 1869, under a Local Board and Town Council, of districts in which salt water, drawn from a tidal river within 2½ miles of its mouth or direct from the sea, has been in use for street-watering. The employment of sea-water has been continuous, except for a short time when hand-pumping was found not to furnish a sufficient supply, and recourse was had to the mains of the local Water Company.

The borough, to the Corporation of which the Author is engineer and surveyor, is divided into two parts by the river Yare. The town portion, or Great Yarmouth, has a population of nearly 40,000, Gorleston and Southtown have a population of rather more than 10,000, making a total of 50,000 for the whole borough. The site is flat and narrow. The whole of the sewage is delivered directly into the river by short lengths of sewers running at right angles thereto; all the sewers have fair falls, the majority ranging between gradients of 1 in 200 and 1 in 400, the flattest being 1 in 500.

The waterworks are in the hands of a private company; the management is good and there is a sufficient supply, indeed during the Author's experience of twenty-two years he has not known of any scarcity. The water is well filtered; great economy is, however, exercised in its distribution; no waste is allowed, and the cisterns of the water-closets are so arranged that only while the closets are in use does the flush continue. In the result the average consumption of water each time a closet is used is less than a gallon; thus very little water finds its way to the sewers. The exact volume used per head has not been published nor is it obtainable by the Author, but it is certainly very small. As a water-closet town, the effect of such a small flushing power in the sewers may be easily imagined when, in August and September, the population is increased by quite 20,000 persons. To the corporation the charge for water is 1*s.* per thousand gallons, with a charge for meters; this is a considerable reduction upon the charge made to private consumers, which varies from 1*s.* 3*d.* to 2*s.* 6*d.* per thousand gallons, according to quantity.

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[1] "Street Watering with Sea Water" is the title of a Paper, by Mr. S. H. Terry, Assoc. M. Inst. C.E., read at a meeting of the Civil and Mechanical Engineers' Society on February 15th, 1888, and published in the Transactions of that Society, Session 1887-8, pp. 46-53.

In 1882 the sewers of the town were found to be in a bad state; they had been allowed to be cut about by persons connecting private drains with them, without any proper supervision, and the Council, acting under the Author's advice, pulled up and relaid some 13 miles of sewers, among which were a number of decayed brick drains several centuries old. In relaying them great care was taken with the private connections, the sewers were thoroughly ventilated, and arrangements were made for flushing with automatic siphons working in brick chambers, fourteen of which, of various capacities, have up to the present date been put in, the larger number being capable of holding 3,000 gallons, while none are of less capacity than 1,600 gallons. The first six of these flushing-tanks were served from the Water Company's mains through a low-pressure meter, each of which supplies from 200 to 300 gallons per hour. A movable iron flushing-tank is placed over the head of the sewer; this tank has a capacity of 3,000 gallons, and was filled at first by hose from the Company's mains, a process which occupied from thirty to forty minutes, while it discharged itself in about one minute. The axles are only of sufficient strength to carry the tank without the water, and the tank is consequently blocked up from the ground. The effect of flushing in this manner has been to thoroughly cleanse such of the drains as it had not been found necessary to take up, and, combined with the siphons beforenamed, it has kept the sewers thoroughly clean; but the great bar to the extension, and even the continuance, of this form of work is the cost of the water.

Previous to 1877 the water had been pumped by hand from wells close to the river, and was as salt as the river water. From 1877 to 1883 the cost of water for flushing and street-watering averaged £404 6*s.* 7*d.* per annum; but in 1884, with only six flushing-tanks at work, the cost to the Corporation, including meter charges and the attendance of a Company's official, was increased to £552 0*s.* 6*d.*, for which sum rather more than 10,000,000 gallons had been delivered. A high-pressure meter was required when the movable tank was in use, or when the were employed with the tanks that were fitted with siphons, and Bailey's Indicators registered the number of times water-carts were filled for street-watering. If the same system had been continued, using 20,000,000 gallons, as the Author considered necessary in order to do the work efficiently, the cost would have been £1,000 per annum.

Such being the position of affairs with relation to the water-supply for purposes of street-watering and sewer-flushing at the end of 1884, the Author attempted to induce the Local Board to lay a complete system of mains for street-watering and sewer-flushing. With the opposition likely to be raised by interested persons, it was necessary that the expense should be kept as low as possible, and the scheme be reduced to the smallest workable dimensions; but it had to be one which would admit of extensions.

The estimated cost was £4,500, for which sum the works were afterwards completed. The annual expenditure was placed before the Council in the following form:—

	£	s.
Repayment of capital and interest	270	0
Consumption of gas for 120 full days of 10 hours, 270,000 cubic feet at 3*s.* 2*d.* per 1,000 feet	42	15
140 days' work for man at 3*s.* 6*d.*	24	10
Oil and waste	5	0
Depreciation of engine and pumps	37	15
Small additions per annum	30	0
Total annual estimated cost	410	0

For this sum of £410 per annum 30,000,000 gallons of water would be raised, 5,000,000 being estimated as necessary for street-watering, and 25,000,000 for sewer-flushing; the supply for baths, flushing-urinals, and fire-extinguishing was not dealt with at the time. The details of the estimate worked out very closely, and have not been exceeded, except that a much larger volume of water was raised which has reduced the cost per 1,000 gallons. The success of the undertaking has been such that the Council readily undertake much larger extensions than were allowed for in the £30 named in the estimate.

The matter was, however, deferred for a time, and experiments were made on long lengths of road, formed both with gravel and with granite. There is only one paved road in the borough; this is about ½ mile in length, and is laid with wood. The effect was closely watched by members of the Sanitary Committee, who ultimately resolved to recommend the Council to apply to the

Local Government Board for powers to borrow the £4,500 required to carry out the work. In the meantime the Water Company were not idle; they obtained a report from two of the most eminent Professors of Chemistry in the country, which they sent to members of the Town Council and to the Local Government Board.

This report was as follows:—

13th October, 1885.

"TO THE DIRECTORS OF THE YARMOUTH WATER COMPANY.

"GENTLEMEN,—At your request we have carefully considered the use of sea-water for road-watering and for sewer-flushing. We have further made numerous inquiries from those who have had experience in its employment for these purposes, and we report to you accordingly.

(*a*) *As to its use for watering roads.*—" There is no doubt (as we should expect) that the road remains damp for a longer period after being watered with sea-water then when fresh water is employed. But even in the face of this advantage its use is clearly not to be recommended.

"1. Because the road in drying, we are given to understand, becomes very slippery and dangerous.

"2. Because the salts present in sea-water are very hygroscopic. Hence in the case of delicate goods (such as silks, jewellery, &c.), injury is certain to arise from the dry dust blown about on a dry day and settling on these goods, becoming damp when the air contains a more than usual quantity of moisture.

"3. Because the occurrence of nuisance from the action of the brine on the organic matter on the road and in the subsoil is certain to be complained of.

(*b*) *As to its Use for Flushing Sewers.*—" Its use is unadvisable.

"1. Because the solvent of salt water on organic matter is very inferior to that of fresh water.

"2. Because where organic matter is in a state of solution in fresh water the addition of brine (sea-water) will effect the precipitation of the organic impurities.

"3. Because (it follows, as a consequence of 1 and 2) if salt water be used for flushing, the quantity of suspended matter will be increased, and the deposit in the sewers likewise increased.

"4. Because sea-water has an energetic action on metals and cements.

"5. Because the sulphates, which are present in large quantity in sea-water, are certain to be reduced by fermentative action, whilst from the resulting sulphides any acid will generate sulphuretted hydrogen. Thus the nuisance arising from flushing-sewers with sea-water may be considerable.

"We are strongly of opinion, therefore, that it is most undesirable to use salt water, either for road-water or sewer-flushing on the two-fold ground of injury to property and injury to health."

In circulating this opinion the Water Company commented upon it as follows:—

"The meaning of this report in plain words is, that the use of salt water for the purposes proposed causes abominable and most nauseous stinks, which must not only be most unpleasant to the inhabitants, but injurious in a very high degree to the town as a watering-place."

The inhabitants had been used to "nauseous stinks," although there had been great improvement through the works already carried out, and it was admitted that more flushing was absolutely needed. The inhabitants were, as a rule, in favour of salt water for street-watering, as many of them recalled the time when the town had been so watered, and the opinion of nearly all the persons consulted by the Author was that the town had not been so well watered since fresh water had been introduced. The subsoil is sand, very light and porous, the roads in the new portion of the town are lightly metalled, and the result was that in summer they were continually breaking up, and frequently with a heavy rain in the early morning dust would be blowing by noon.

At the inquiry held before Mr. Codrington, M. Inst. C.E., the Inspector appointed by the Local Government Board, Mr. H. P. Boulnois, M. Inst. C.E., gave evidence in favour of the scheme. No opposition being offered, the Council obtained the consent of the Local Government Board to borrow the money for a term of thirty years, and the works were carried out in accordance with the Author's plans.

The plant comprises an Otto gas-engine of 8 HP., to the foundations of which are attached two pumps of 12 inches in diameter, with a length of stroke of 15 inches, doing work equal to 25,000 gallons per hour. A brick tower carries a cast-iron tank with a capacity of 23,000 gallons, the height of which to the floor of the tank is 44 feet above low-tide level, and about 12 feet above the highest part of the town. The depth of the tank is 8 feet, so that there is a head, not allowing for friction in the pipes, of 20 feet with a full tank, in the highest parts; but more than three-fourths of the area of the town lie so much lower that this head is quite 30 feet, and the pressure, wherever the salt water is put into private houses, has been found to equal that of the town fresh-water supply. The cast-iron suction-pipe is 8 inches in diameter and flanged, laid under the floor of the jetty, at the foot of which the pumping station is built. The pipe before it enters the building passes through a cast-iron intercepting tank, 7 feet 6 inches in diameter, and 15 feet in length. This tank requires emptying from sand about once in twelve months, and in this way the Author has saved the plungers of the pumps from being cut. The rising-main is 8 inches in diameter to the tank, which is 700 feet from the pumps. The distributing-mains, of which the scheme comprised about 6¼ miles, since increased to about 9 miles, are 7 inches, 6 inches, 5 inches, 4 inches, and 3 inches in diameter, and almost every public sewer in the town is now flushed. The pipes are coated with Doctor Angus Smith's composition, and show no signs of deterioration. They are jointed in the usual way with spun-yarn and lead. The hydrants for street-watering are placed in such a way that the horse shall travel as small a distance as possible with an empty cart. This distance was fixed at a maximum of 800 feet, after experiments with the carts and vans then in use, and has been the means of a great saving in time of cartage. The number of hydrants first put in was forty-two, since increased to forty-eight. Forty valves, varying from 6 inches to 3 inches in diameter, were put in for sewer-flushing. The connections with the fixed tanks were made with 3-inch pipes and valves, so that the tanks could be charged rapidly if required. The practice is, however, to leave the valve partly open, so that a flush goes off two or three times a day in summer, and once a day in winter; but when any general flushing is arranged for, five or six tanks are sometimes timed to go off simultaneously, so as to give a complete flush in the main sewers. The number of valves has been increased by twenty since the completion of the works.

The success of this undertaking has been such that, about three years after its completion, the Council adopted and carried out a similar scheme for the portion of the borough on the other side of the river. This installation is similar in point of construction for flushing-arrangements and watering, but two 4-HP. Otto gas-engines, not fully employed for sewage-pumping, have had two pairs of 6-inch pumps added, a concrete tank of 74,000 gallons capacity was constructed on the highest part of that portion of the borough, and upwards of 4 miles of distributing mains have been laid, the majority of which are 6 inches in diameter. The total cost of the works was £3,000, making the whole capital expenditure for sea-water supply in the borough £7,500.

Before the first scheme was submitted, the Author wrote to the engineers and surveyors of a majority of sea-side towns, and the following gives, in a condensed form, the information which he was then able to lay before the Council, with the original scheme.

Birkenhead.—"One spread of salt water on the surface of a street or road is equal to about three spreads of fresh water, as the latter under the heat of the sun evaporates, whereas the salt water leaves a crust on the surface and keeps down the dust for a considerable time. We have not yet flushed our sewers with salt water."

Hastings.—"Sea-water has been used in this town for some years for street-watering and sewer-flushing, and no inconvenience has been found to arise. There is, perhaps, rather more mud on the roads during the autumn; but, on the whole, I believe that sea-water has a good sanitary effect on both roads and sewers."

Worthing.—"Many of our streets are watered with sea-water, and have been for years, the effect upon roads is to bind them together almost like cement; dust is never seen on these roads when dry, and sea-water keeps damp at least as long again as fresh water. Such an argument as sea-water acting upon sewage so as to make it offensive is simply absurd."

Eastbourne.—"We thought of using sea-water some years ago, but as there was a general objection to it we gave it up. From what I have seen of its use my opinion is that it materially assists the solidifying of a road."

Brighton.—"We do not use sea-water for street-watering, but we use it for flushing our main intercepting sewer, and if used in sufficient volume it is not offensive."

Blackpool.—"This Corporation has used sea-water for street-watering and sewer-flushing for some time, and I find no complaints arise whatever, but sea-water makes sett paving slippery."

Ryde.—"I can state confidently, after upwards of thirty years' experience in the use of salt water for watering roads, that so far from deteriorating macadamized roads it hardens the surface, so much so, that during the recent dry summer we found that in streets with a gradient of 1 in 12, when it was necessary to water a second time in the day, we were compelled to use fresh water, otherwise the streets would have become too slippery.

"Doubtless after a long course of salt water on a level road, when rain first comes the surface will be a little dirtier than if fresh water had been used.

"We find it pays to use salt water when a load of water costs twice as much as fresh.

"With reference to flushing-sewers, I am disposed to think that the contention of your Water Company is right, but in this matter I have had very little experience."

Rhyl.—"Sea-water will not injuriously affect macadamized roads, but have a good effect."

Torquay.—"I have used sea-water for street-watering upon macadamized roads for several years, and do not find any inconvenience; but if there is any difference between salt and fresh water I think the salt water is preferable.

"I do not use salt water for flushing, except very rarely in the low level, and then I do not find any smell more offensive than at other times."

Margate.—"Had no special means of raising salt water, and so gave it up; when used, one load went as far as three loads of fresh water."

Plymouth.—"All the low levels are watered with it; consider that two loads of fresh water are not equal to one of salt."

South Shields.—"One load of salt water equals four loads of fresh."

Tynemouth.—"Has a very good effect upon street surface, as it hardens the surface of macadamized roads; we use it for watering, flushing, and baths."

Barrow-in-Furness.—"Use salt water for street-watering; when fresh water used it took twice the quantity."

Ilfracombe.—"Used sea-water formerly, and contemplate doing so again. It retains its effect twice as long as fresh water. and it is very binding."

In addition to the foregoing, the following opinion of Mr. H. P. Boulnois may be quoted:—[1]

"Watering the streets with sea-water should be adopted wherever it is feasible, as it not only gives a delightful freshness to the air and dispels iodine, but it also causes the surface of the street to maintain its humidity for a longer period than when fresh water is used, as it impregnates the soil with hygrometric matter. This has been often attempted artificially, by adding common salt to the water used for watering."

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[1] "The Municipal and Sanitary Engineers' Handbook." By H. Percy Boulnois. 8vo. London, 1883, p. 247.

With this information before them, the Council undertook the construction of the works as before described; their installation has proved an unqualified success. A larger volume of water has been raised than was at first estimated; this has reduced the cost of the water to about 2½*d.* per 1,000 gallons.

STREET-WATERING.

Since the construction of the works, the consumption of water for street-watering has been less than 5,000,000 gallons at 2½*d.* per 1,000, instead of 7,000,000 gallons at 1*s.* per 1,000, reducing the cost of water for this purpose from £350 per annum to £50, also saving the cost of distributing 2,000,000 gallons, or a further reduction of £75, making the saving for street-watering about £375. In addition, there is a considerable saving on the gravel- and flint-made macadamized roads. There are no accounts which can accurately show this, but after watching these roads and careful consideration, the Author's opinion is, that roads of this character can be maintained at a cost of about 15 per cent. less by using salt water than fresh water, as their surfaces are much improved in summer time. Neither are there any evil effects observable on the granite-made roads. The Author's observations lead him to the conclusion that salt water does not injuriously affect them in any way; that they are improved, or the cost of their maintenance reduced, he does not contend, but he is certain that their cost is not increased.

During the summer months the dust is kept under by the adhesive quality of the salt water, and in the early autumn, if the surface coating is removed by broom upon the appearance of the first frost, no evil effect whatever is traceable to the use of sea-water.

The complaints which, under the old system of watering with fresh water, used to be loud and frequent, are now rarely heard, and the watering of the town is much more satisfactorily carried out with a considerably reduced expenditure. No complaints have at any time been heard from shopkeepers, and jewellers have expressed their approval and asked for more night, the need for street-watering on the Sunday is avoided.

The three reasons urged by the chemists in their report to the Water Company, why sea-water should not be used for street-watering, have given no cause for anxiety; in no case have any complaints been made of the slipperiness of a road which could be attributed to its use. As before stated, no shopkeepers have ever complained of injury to goods, and nuisance owing to the action of the brine on the organic matter has never occurred.

Sewer-Flushing.

The Author has before stated that the effect of flushing with salt water has been to thoroughly cleanse the sewers of the town, and with the five years' experience he has had, he is able to assert, that no nuisance from its use has been created; while, owing to its greater specific gravity, he considers it more valuable as a flushing agent. Its effect in the Yarmouth sewers has been to reduce, and in fact almost entirely to prevent, the generation and accumulation of sewer-gas. Sewers which could not be entered by the sewer-men until the manhole covers had been opened several hours, can now be entered by them, and have been entered by the Author immediately on the removal of the manhole cover, without any inconvenience. An 18-inch pipe sewer, with a gradient of 1 in 300 from the "Butchery," which it had been found impossible to keep free from deposit, is now kept thoroughly clean by two flushes a day from a 3,000-gallon tank with a 12-inch siphon, which, at the time of its discharge, fills the sewer to rather more than two-thirds of its capacity. This the Author thinks is one of the most severe tests which the use of sea-water can have, as the blood, more than brine, has the effect of precipitating the solids in the sewage. Generally, throughout the town the same effects take place, sewers which it was necessary to cleanse once a year by rods or other mechanical means, are now kept thoroughly clean by flushing-power only. As far as possible the Author has arranged that the sewers, when they are flushed, shall run about three-fourths full, as giving the largest weight of water with the smallest amount of friction on the perimeter of the sewer. In large sewers of more than 2 feet in diameter, or if egg-shaped of more than 30 inches in height, this has not been obtained, and yet in these the effect has been perfectly satisfactory.

Returning to the comments of the chemists previously quoted, there are now no deposits of any sort in the town sewers except in three or four of the largest, and there the deposit has been reduced to half what it was before the introduction of sea-water for flushing; thus the first three contentions, that its use for flushing was unadvisable, have, so far as the experience of the Great Yarmouth authorities are concerned, proved erroneous.

The fourth contention, that it would have an energetic action on metals and cements, could not much affect the sewers of the town, when the only metal in them was in the penstocks at their mouths, already in salt water. Some tens of thousands of tons of salt are imported into the town for the fishing industry, and in a great measure this salt finds its way to the sewers without doing any appreciable damage. The siphons are of galvanized sheet-iron, but they have required no repairs since they were put in.

To the fifth contention respecting sulphates in sea-water no evil effects are traceable; the town does not possess manufactories, and no acids are discharged into the sewers.

No evil effects are traceable under any of these five contentions or under any others, but in the Author's opinion the position of the town is remarkably well adapted for these works, the short lengths of the sewers and the fair gradients of the majority of them give no time for fermentative action, as the charge from the furthest flushing tank reaches the outfall within forty minutes. The great reduction of sewer gas may be considered to have been effected by two causes, first by the absence of the deposits to generate the gases, and secondly by the motion of the flushing water in the sewers, which completely changes the air therein.

The cost of this work has been less than it would have been to mechanically cleanse the sewers, while its benefits can have no monetary value placed upon them; about 40,000,000 gallons were used last year for this purpose, the cost of which was about 2½*d.* per 1,000 gallons including all charges.

The urinals throughout the town are flushed with the water, and give every satisfaction, the quantity consumed for this purpose being about 15,000 gallons per day.

FIRE-EXTINGUISHING.

In the mains on this scheme there is a head equal to, and in excess of, that which is available in the Water Company's pipes during the time the domestic supply is being drawn off, but in a case of a large fire this supply can be cut off from all parts except in the particular district where the fire is situated, and this gives an advantage of about 10 feet more head than there would be in the sea-water mains. The salt water has never been used for extinguishing fires, but a supply is always available in case of failure of the Water Company's supply. The Author, however, does not recommend its use for this purpose, as he considers a dwelling-house would not be equally habitable after its walls had been saturated with sea-water; the mains are however extended by the river-side at the Fish Wharf belonging to the Corporation, for extinguishing fires on fishing-boats and other crafts where the mains of the Water Company were not of the requisite size to give a sufficient head for this purpose.

As to its use for baths, unfortunately, about a century and a half ago, the then Town Council granted a monopoly of the right to use sea-water for bathing purposes, on what was called the Council's waste land. This includes nearly the whole of the land outside the town walls, where now the best portion of the residences and lodging-houses are built. It was, however, provided that baths should be erected, and although it is asserted that neither party carried out the terms of this agreement, and that it is null and void, the right which is now claimed somewhat interferes with private individuals taking a supply of sea-water into their houses, as they are afraid of finding themselves involved in legal proceedings with the present proprietors of the baths. Eight persons have, however, laid on the water for baths and for flushing their drains, the Council giving every facility for its use, and charging for it only 10*s.* per annum for each house where the rent does not exceed £50 per annum, with an increase of 1*s.* for every £10 additional rent. There are no swimming-baths in the town; but should the Corporation ever provide them there is very little doubt that sea-water from the existing works will be used for this purpose. The Author has been in communication for the past seven or eight years with most of the borough engineers of seaside towns, and wherever sea-water has been employed he has received answers approving its use.

A large quantity of information has been collected since that obtained by the Author by the engineers of Ipswich, Bournemouth, Edinburgh, and Birkenhead, and by the Medical Officer of South Shields. With the exception of that from Hastings, the information is in favour of the employment of salt water.

Where the water-undertaking is not the property of the Local Authority the Author is decidedly of opinion that an independent supply, drawn from some stream or other source if the sea is not available, would result in a great saving. Few towns are so placed as not to have such a supply available, and there is little doubt but that a reasonable quantity of, say 40,000,000 gallons per year, could be raised and distributed at a cost ranging from 2*d.* to 4*d.* per 1,000 gallons, thus placing the Local Authority in an independent position for flushing their sewers.

The Author considers that the reduced cost of such a supply, compared with the charges of most of the Water Companies, is due to the fact that no expensive filtration is necessary, and that the capital expenditure on long lines of large mains is saved, while the low rate of interest at which the Local Authorities can now obtain their loans is much less than the rate of dividend which Water Companies usually distribute.

The Paper is accompanied by three drawings, which may be consulted at the Institution.

(Students' Paper No. 291.)

"On some Forms of Petroleum-Engines."[1]

By Richard John Durley, B.Sc., Stud. Inst. C.E.

In this Paper the Author proposes to give an outline of the progress recently made in the use of petroleum as a source of power in internal-combustion engines, by describing some of the modern forms of such motors.

Petroleum, as it occurs in nature, may be considered as a mixture of hydro-carbons of different densities in various proportions. The heavier oils are, as a rule, found in shallow wells, whilst deeper borings generally yield lighter products. The hydrocarbons which are the chief constituents of crude petroleum, have the general formula $C_n H_{2n+2}$. The first member of this group is marsh gas, $C H_4$, which is followed by a series, increasing in density as the carbon increases, and passing from a volatile petroleum-spirit, or benzoline, through heavier oils, to solid compounds. When obtained from the wells, crude petroleum is subjected to distillation at successively increased temperatures. By this means three classes of oil (roughly speaking) are produced, namely, petroleum-spirit, density 0·7 to 0·73; illuminating-oil, density 0·73 to 0·82; and a residue of higher density. Oil of the first two classes is commonly employed in internal-combustion engines, and it will be obvious that the gas-producing arrangements of the engine must differ according to the nature of the oil intended to be used. Other things being equal, a motor employing the heavier oils is preferable, on account of their greater safety and convenience in handling. Some forms of oil-engine are adapted to consume not only oils belonging to the second class, but also substances of the character of Scotch shale-oil, creosote, &c., of density ranging up to 0·9. Although cheaper, fuel of this nature usually entails inconvenience and expense, on account of the dirt inseparable from its use.

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[1] This Paper was read at a meeting of Students on the 8th of April, 1892, and has been awarded a Miller Prize, Session 1891–92.

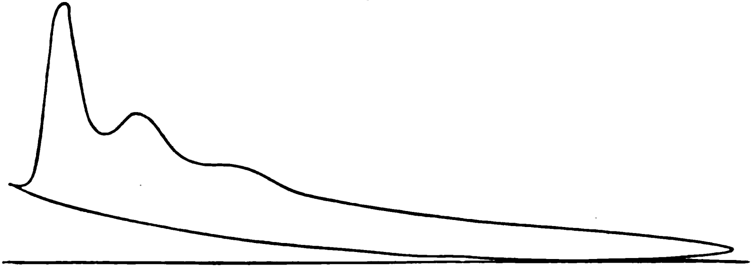
Internal-combustion oil-engines are essentially gas-engines, which use, instead of coal- or producer-gas, a mixture of air and petroleum-spray or vapour in proper quantities to form a combustible charge that is exploded in the working-cylinder. As in the case of gas-engines, the most successful oil-engines in practice are single-acting and of the compression type; that is, the charge of vapour and air is compressed, either in a separate pump or in the working cylinder, before ignition takes place. In the latter case, work is done on the piston only every alternate revolution, whilst in some engines another working stroke is sacrificed for the purpose of clearing burnt gases from the cylinder, by drawing in and expelling a charge of air. Ignition then occurs once every third revolution. In the early days of gas-engine construction, many inventors sought a supply of gas from petroleum. A number of the old specifications mention that volatile hydrocarbons may be used for the preparation of the explosive charge. The progress of the oil-engine has thus been intimately connected with that of the gas-engine, and a historical survey of the development of the one would necessarily cover the same ground as that of the other.

The modern petroleum-engine comprises the following parts:— 1. Oil-reservoir; 2. Carburetter, or apparatus in which the oil is converted into vapour; 3. Air-admission and mixing apparatus in which the combustible charge is formed; 4. Compressing-pumps for the air and charge; 5. Working-cylinder and gear; 6. Valve-gear; 7. Igniting-arrangement; 8. Governor; 9. Starting-gear. As will be seen, the functions of two or more of these parts are frequently performed by one, and (as in the case of engines using the lighter kinds of oil) it is possible to dispense with the carburetter, the spirit being injected directly into the working cylinder. The differences in the construction and mode of action of various types of engine will be best understood from a brief description of some of them.

The Simplex petroleum-engine, although properly a gas-engine, is provided by the makers, Messrs. Matter, of Rouen, with an ingenious form of carburetter, which enables it to use light petroleum-spirit very successfully. The engine is constructed after patents taken out in 1884 by Messrs. Delamare-Deboutteville and Malandin, and has worked well in practice. In appearance it is of the usual gas-engine type (Fig. 1, Plate 4), having a single-acting, open-ended, water-jacketed cylinder, and a side shaft (geared 2 to 1) for actuating the valve-gear. Admission and ignition are effected by a simple form of slide-valve, whilst the exhaust-valve is of the mushroom type. The action is illustrated in Fig. 2. From the carburetter the vapour passes through a mushroom valve A into a mixing chamber B attached to the slide cover, where it meets air entering by a separate pipe C. The slide-valve opens the admission-port just as the piston begins to move forward, and the charge of vapour, together with a quantity of air, passes into the compression-space D of the cylinder. Besides the admission-port E, the slide-valve also contains an oblique passage F which, at the proper instant, makes a connection between the cylinder and the electric igniter G. A constant stream of sparks is passed between the platinum points by means of an ordinary induction-coil, worked by a bichromate battery. One terminal is insulated by means of a porcelain plug; the other is attached to the slide-cover. After each explosion, the passage F remains filled with burnt gases which would delay or prevent ignition, and are therefore expelled in the following way. On the back of the slide-valve is a small vertical groove H open to the air at the top. As the ignition-port opens, this groove comes opposite a small hole, J, leading from the spark-chamber to the back of the slide-valve. A passage to the external air being thus opened, the compressed charge in the cylinder blows through the passage F and is ignited. The exact instant of ignition is, of course, determined by the size of the small hole J. It will be seen that the gas-admission valve is opened by a knife-edge carried by the slide-valve. The governor-gear is so arranged that this knife-edge is displaced whenever the engine attains an abnormal speed, thus failing to admit any charge until the engine slows. The "air-governor" consists of a small cylinder carried by the slide-valve stem, which is driven by a crank on the end of the side shaft N. The cylinder contains a piston K secured to the slide cover. The small screw at L throttles the opening by which air can escape from the cylinder. The knife-edge is carried by the piston-rod of a smaller cylinder M at right-angles to the pump-cylinder. If the pump draws more air than can pass through the hole at L, the piston M is pressed outwards, the knife-edge does not hit the stem of the admission-valve, and the engine misses a stroke.

The Simplex carburetter, Fig. 3, both produces a supply of vaporised petroleum-spirit for the engine, and rejects the residue that is of too high a density for use. From the reservoir A, furnished with a graduated cock which can be closed by the governor, a stream of oil trickles. This, together with a supply of water from the cylinder-jacket at about 120° Fahrenheit, runs down a spiral horse-hair brush B in a tube C jacketed with warm water. The vapour, water and unused oil, pass into a separating-chamber D, from which the gas passes to the engine by the vapour-pipe E, provided with a non-return valve to prevent backward ignition. The water and refuse oil overflow by the siphon F. In order to prevent splashing consequent upon a sudden diminution of pressure in the chamber D, a perforated cork float G is used. The advantage of a carburetter working on this system is, that the gas-supply to the engine is of uniform quality, while dirt and incrustation in the slide and cylinder are avoided. The consumption of petroleum-spirit of density 0·65 to 0·7, is about 1·4 pint per indicated horse-power per hour, costing about 3·9 pence (in France). A Simplex engine indicating about 9½ HP. at 160 revolutions, has a stroke of 15¾ inches, and a diameter of cylinder of 7⅞ inches. The compression-space is about 30 per cent. of the total volume of the cylinder. The exhaust-temperature is about 350° Centigrade, and that of the jacket-water on leaving the engine is about 70° Centigrade, the amount of jacket-water required being 44 gallons per hour. An indicator diagram of the Simplex engine is shown in *Fig. 1.*

Fig. 1.



Simplex Petroleum-Engine.

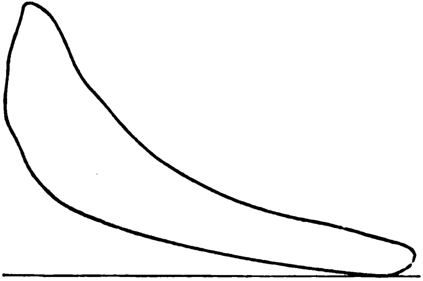
Typical Indicator-Diagram. Revolutions 195.

Another engine using light petroleum is made by the Gasmotoren Fabrik, of Deutz, near Cologne. It is practically the same as the Otto gas-engine, but is furnished with an electric igniter and mushroom valves. The governor-gear is of the usual type; the sleeve on the side shaft that carries the cam by which the gas-regulating valve is worked, being moved along the shaft so as to miss the valve-lever, and thus prevent a charge of gas from being drawn. The general arrangement of the engine is shown in Fig. 4, Plate 4, and the igniting apparatus in Figs. 5 and 5*a*. At the back of the cylinder, under the side shaft bearing, is fixed a built-up permanent magnet A, between the pole-pieces of which is a rotary armature. A bent lever B on the armature-spindle, is so arranged that, after being partly rotated by the cam C on the side shaft, the armature is quickly turned back by the spring D and causes an electric current to be generated. A porcelain plug E carrying a steel wire about $\frac{3}{16}$ inch in diameter, is fixed in the end of the cylinder; and one terminal of the armature is connected with the outer end of the steel wire. A small shaft F also passes air-tight through the end of the cylinder, and is connected with the other terminal. On this shaft a contact-lever, inside the cylinder, is pressed against the insulated wire at E, by the action of an external spring G. The shaft F is connected with the lever B in such a way that, as the armature flies back, contact is broken at E, and a spark passes. During the rest of the stroke the contact-lever is touching the insulated wire, and the surfaces between which the spark passes are kept clean. Ignition takes place at the dead-point. The gas-regulating valve is shown at H, the admission-valve at J, and the exhaust-valve at K. The two latter are both mushroom valves, the admission-valve works automatically and is closed by a spring, whilst the exhaust-valve is worked by a cam on the side shaft. Small covers, L and M, are provided for the examination of the admission-valve and igniter, and of the exhaust-valve, respectively. The side shaft is geared 2 to 1 from the main shaft. The lubricator is of the usual "Otto" type. The cylinder and compression-space are water-jacketed.

The carburetter employed with this engine, Fig. 6, consists of a cast-iron vessel surrounded by a water-jacket A, through which water from the cylinder-jacket is passed. Spirit is pumped from a reservoir by hand, as required, through the cock B; and a float C indicates the amount of liquid in the carburetter. An air-pipe D, fitted with a wire-gauge strainer outside, and dipping below the surface of the oil, is arranged so that the air passes through the liquid in fine jets, becoming in this way saturated with vapour. The gas-pipe E leads to the engine, and is furnished with a cast-iron box F filled with small flints, and also passes through a non-return valve G for security in case of backward ignition. A safety-valve H is also fitted. Below the carburetter is arranged a cast-iron exhaust-box J, through which more or less of the waste gases can be passed, to assist in evaporating the spirit. In starting an engine of this type, it is necessary to turn the fly-wheel by hand with sufficient rapidity to cause the igniter to yield a spark. The engine requires turning until enough vapour has been drawn from the carburetter to enable a working-stroke to be made. The jacket-water should leave the engine at a temperature of about 170° Fahrenheit. In working, the gas-cock is kept full open and the air-cock adjusted as required. The Otto petroleum-engine is not suitable for powers above about 8 HP., but in these small sizes has given satisfaction. The consumption of petroleum (of density 0·7) in actual working is about 1·3 pint per brake horse-power per hour, costing, in Germany, 1·8*d.*

The Lenoir petroleum-engine, made by Messrs. Rouart Frères, of Paris, has been chiefly used as a portable motor for agricultural use, Fig. 7, Plate 4. The cylinder is water-jacketed, and has a separate compression-chamber bolted on, the joint being made with non-conducting composition. Admission and ignition are effected in a separate box arranged at the side of the cylinder (Fig. 8). The admission-valve, A, is a simple mushroom valve, which lifts automatically as the piston moves forward; the air-supply enters through a perforated plug B just below the admission-valve, and the electric igniter projects into the admission-port C in the side of the cylinder. A small centrifugal pump circulates the water in the jacket. The carburetter (Fig. 9) consists of a cylinder rotated by the engine, and mounted on a hollow shaft through which air enters and leaves it. The inner surface of the cylinder is provided with small troughs A A which carry up the spirit, and cause it to drop through the current of air in thin streams. An indicator diagram of the engine is shown in *Fig. 2.* Trials carried out by Mr. Tresca on a 4-HP. Lenoir engine, have shown a consumption of 1·12 pint of oil per indicated horse-power, or 1·51 per brake horse-power per hour, on a four-and-a-half-hours' run. The charge was compressed to about 75 lbs. per square inch before ignition, and the maximum pressure in the cylinder was from 180 lbs. to 200 lbs. per square inch.

Fig. 2.

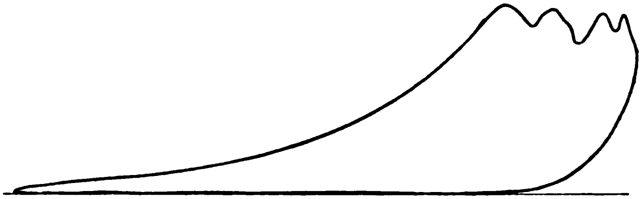


LENOIR PETROLEUM-ENGINE.

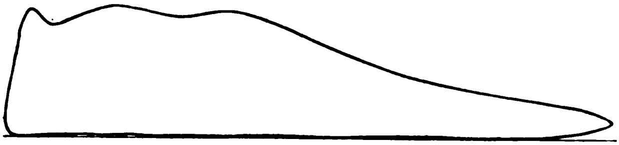
Typical Indicator-Diagram. Revolutions 158.

The Brayton petroleum-engine (Figs. 10, 11, 12, Plate 4), is of a type distinct from those already described. Not only does it use oil of high density, up to about 0·85, but the heat is developed in the cylinder, not suddenly and at approximately constant volume, as in the ordinary so-called explosive engines, but gradually and at constant pressure up to the point of cut-off, expansion then taking place as in a steam-engine cylinder. The engine is interesting more on account of its working with this cycle than on account of its utility. It is single-acting, and has separate working- and compression-cylinders. The piston is of the trunk type, and contains a self-acting air-admission valve A, Fig. 11. A burner-nozzle B is supplied with a constant flame by means of an oil-and-air jet, which keeps a small coil of platinum wire in an incandescent state. The burner is fixed in the cylinder so as to be clear of the piston when at the top of its stroke, and to be directly in the path of the mixed oil and air as it enters from the admission-nozzle C. The lever D operates both the admission valve E and the annular exhaust-valve F; both are kept closed by springs when the lever is in its middle position. The lever derives its motion, by a double cam, from an auxiliary shaft geared 2 to 1 from the main shaft. The compression-cylinder supplies air to an air-reservoir, to the burner, and to the admission-chamber G. An oil-pump is driven by an eccentric on the auxiliary shaft, and injects a charge of oil to the chamber G every alternate revolution. When starting the

Figs. 3.



PUMP CYLINDER.



MOTOR CYLINDER.

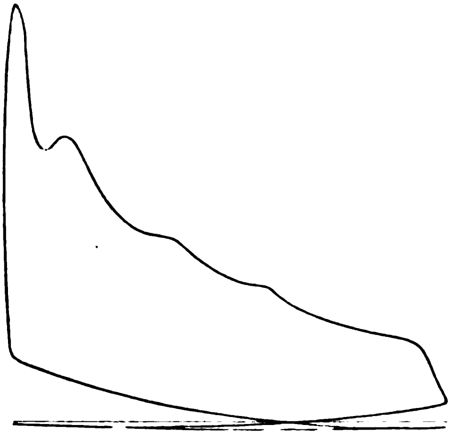
BRAYTON PETROLEUM-ENGINE, 1872.

Typical Indicator-Diagrams. Revolutions 200.

engine, the pump can be worked by hand. The reservoir of the burner B is supplied with oil through the hole at H, as required. A sighting-port K is provided in the cylinder for the purpose of examining the nozzle, and lighting the burner before starting the engine. The amount of oil injected into the admission-chamber is regulated by a centrifugal governor, which varies the stroke of the pump-plunger. This is effected by a sliding cotter A, which is pushed into, or withdrawn from, the space between the eccentric-rod B, and the end of the pump-plunger C. Motor- and pump-diagrams of the engines are shown in *Figs. 3.*

The Priestman oil-engine may be regarded as a typical form of the engine which is likely to be generally employed in the near future in England: namely, an engine of the "Otto" type, but provided with apparatus enabling it to successfully consume the heavier, and safer, kinds of oil. In the Priestman engine even creosote has been used; but the best results are obtained with oil of density of 0·8, or thereabouts. Fig. 13, Plate 4, shows the general arrangement of the engine as at present made (November, 1891). The vaporizer, Fig. 14, is a thin cast-iron box with double walls, containing an inner chamber A, and an outer one B, through which the exhaust passes on its way to a silencing-box in the foundation. A spray-burner is placed under the vaporizer for the purpose of heating it before starting the engine; this is facilitated by a sheet-iron hood C, and by the provision of passages D D cast in the vaporizer. From the openings E E pipes lead to the valve-chest. A drain-cock is provided on the bottom of the vaporizer for the removal of surplus oil, and the exhaust leaves by the branch F. Ignition is effected electrically. A separate box contains a bichromate battery and an induction-coil, and in the primary circuit of the latter is placed a contact-breaker worked by the side rod, as shown in Figs. 15. The secondary circuit of the coil passes through an igniter, the platinum points of which are inside the cylinder in the compression-space, and about 5 inches from the end of the cylinder. The terminals are about $\frac{3}{32}$ inch apart, and are insulated from the cylinder by porcelain plugs fixed with plaster of Paris. The spray-making nozzle is attached to the end of the vaporizer, the nozzle itself being of such a form that the stream of oil has the air blown transversely across it, and is thus finely divided. Fig. 16 illustrates this. The supply of oil is regulated by a cock A worked by a centrifugal governor, which is, however, unable to close the oil-pipe entirely. The small opening in the plug leads into a fine notch *a*, and in this way the amount of oil passing is regulated to a nicety. The plug of the governor-cock is prolonged to form a spindle for a throttle-valve B working in the extra air-supply passage C, through which the engine draws the amount of air necessary to form an explosive mixture of the right composition. On the air-passage is also a reflux valve D and a rotary plate, or shutter, E, by means of which the air-supply can be cut off altogether at starting. The air-supply enters the vaporizer by means of the perforations F F. For the purpose of starting the engine, a hand-pump is provided, so that air may be forced into the oil-reservoir, and the burner under the vaporizer be lit. After this has been burning a few minutes, the oil-and-air jet is turned on to the vaporizer by means of the three-way cock on the top of the oil-reservoir, and, when a charge has accumulated, the engine is turned by hand until a working-stroke is made. Care must be taken that the extra air-supply is shut off (by means of the shutter E) until the engine is fairly started, otherwise the first few charges will not be rich enough. It is also advisable to move back the fork of the contact-breaker, by means of an adjusting-screw to which it is fixed, so that during the first two or three strokes ignition may take place somewhat later than normally. The Priestman engine uses the ordinary "Otto" working cycle, and no scavenger-charge is employed. Ignition takes place usually at the dead-point, and, in normal working, the charge consists of 0·015 cubic inch of oil to

Fig. 4.



PRIESTMAN OIL-ENGINE.

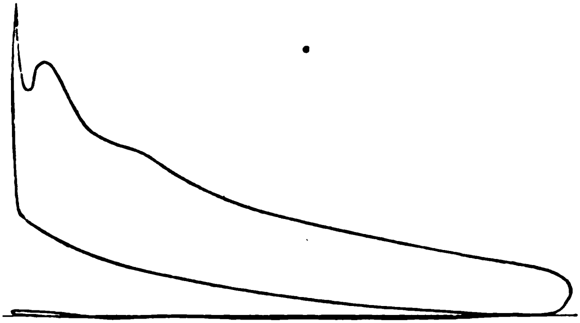
Typical Indicator-Diagram. Revolutions 184.

191 cubic inches of air. *Fig. 4* shows an indicator diagram of this engine. The horizontal engines make between 160 revolutions and 200 revolutions per minute, according to size; with an air-pressure in the oil-reservoir ranging from 5 lbs. per square inch in the smaller, to 15 lbs. per square inch in the larger sizes.

The oil-engine recently produced by Messrs. Crossley, is, in external appearance, very similar to their well-known Otto gas-engine; with the addition, at the back of the cylinder, of a vaporizer A, Figs. 17 and 18, Plate 4, and apparatus for preparing the explosive charge. The vaporizer is a cast-iron chamber, connected with the cylinder by the oil-gas admission-valve, and has beneath it the horizontal ignition-tube B. Both are heated by the flame of an oil-burner. One end of the hot tube is in connection with a timing-valve C that leads to the cylinder; and at the other end is a snifting-valve D, so that any deposit or burnt gases may be blown out of the tube after each explosion. The timing-valve is merely the flattened end of a small spindle, which is moved by a cam on the side shaft, so as to open a passage from the tube to the cylinder at the proper time. The oil-admission valve E is of the mushroom type, and admits gas from the vaporizer into the cylinder; it is driven by a hit-and-miss pendulum governor F, of similar form to that used in the Otto gas-engine, and its spindle communicates motion, by a small lever and shaft, to the oil-pump. This latter has two plungers, the stroke of which can be adjusted independently; one of these injects oil directly into the vaporizer, and the other constantly pumps into the reservoir G, from which the burner is supplied. A return-pipe brings back any excess of oil from the lamp H. This contains a shallow oil-vessel, in the centre of which is an air-jet, surrounded by an annular opening through which a current of air is drawn by the jet, becoming at the same time sufficiently charged with oil to enable it to burn with a strong flame. The burner is supplied with air by an air-pump J, which has a slack piston that requires no lubrication, and is driven by the lever that operates the exhaust-valve K. The pump being single-acting, the blast is maintained by a chamber covered with an india-rubber diaphragm. The exhaust-valve is arranged and worked as in the Otto gas-engine. The air-admission valve L is self-acting, and is placed on the side of the cylinder. In starting the engine, the oil-pump is moved a few strokes by hand, so as to ensure the presence of a little oil in the lamp and vaporizer, and the burner is lighted, the blower being worked by a treadle. In a few minutes the vaporizer and tube are sufficiently hot to give an explosion on turning the engine by hand, after which working proceeds in the ordinary way.

The Hornsby oil-engine possesses a distinguishing feature in that no igniting- or timing-gear is employed, oil being injected directly into a heated vaporizer communicating with the cylinder. The "Otto" cycle is used, and the engine, so far as its working parts are concerned, is of the type usual in such motors. There is no side shaft; but a countershaft geared 2 to 1 with the main shaft, carries cams which operate the exhaust-valve lever and the oil-pump. The latter can have its length of stroke adjusted by means of a screw, and pumps the charge for each stroke into the vaporizer just as the crank passes the dead-point. The vaporizer is a cast-iron chamber, provided with internal ribs to increase its surface, and opening direct into the cylinder. No external heat is supplied to the vaporizer while the engine is running, the temperature being maintained by the combustion of the charge within; while comparatively little heat is conducted from it to the cylinder. Fig. 19, Plate 4, exhibits the construction of the engine. The air-admission- and exhaust-valves are contained in a box under the cylinder; the former is self-acting, being closed by a light spring. A lubricator is provided for the piston, and the cylinder is jacketed in the usual way. The oil-reservoir is situated in the foundation. A lamp and hand-fan are used for heating the vaporizer before starting the engine. The lamp consists of a small chamber filled with oil up to the level of the air inlet-pipe. The oil is led through a plug-hole provided for the purpose; and, on working the fan, a strong flame plays directly on the bottom of the

Fig. 5.



HORNSBY OIL-ENGINE.

Typical Indicator-Diagram. Revolutions 180.

vaporizer. The engine is governed by closing a valve on the oil-pump suction-pipe. The indicator-diagram, *Fig. 5*, from a Hornsby engine, shows an unusual amount of compression; and this explains why the engine is enabled to work without any igniter. The oil enters the vaporizer just as the air contained in it has reached a high temperature, and therefore burns readily. This engine has not at present reached such an advanced stage as to enable any useful particulars of its performance to be given.

The engines briefly described above are a few of the many forms of oil-engine which have been brought forward; and they have been selected as either typical examples, or as engines likely to come into more extended use in the immediate future. That the design of petroleum-engines is at present in an experimental stage, is shown by the number of new types which are continually being proposed. The subject is one in which great progress may be expected to result from the attention that is being paid to it. In conclusion, the Author wishes to express his indebtedness to those firms who have allowed him facilities for examining their engines, and have supplied him with the information from which the illustrations have been derived.

The communication is accompanied by twenty-six tracings, from which Plate 4, and the *Figs.* in the text have been prepared.

(*Paper No. 2633.*)

"The Electric Lighting of Danger Buildings."

By Charles Frewen Jenkin, B.A., Assoc. M. Inst. C.E.

The danger from ordinary electric lighting, carried out in accordance with such rules as those drawn up by the Phœnix Fire Office, will soon be able to be estimated from the statistics of the Fire Offices. It is probably very small, but is certainly not non-existent; and it must be remembered that for every fire of sufficient magnitude to come under the notice of a Fire Office, there must be many trifling cases of fire, overheating, and sparking, any one of which would be sufficient, in a dusty powder building, to cause a disastrous explosion.

These considerations show the necessity for taking much greater precautions in danger buildings than in others. At the same time, the danger arising from electric light varies immensely in different classes of buildings, all of which may come under the definition of "Danger Buildings" as given in the Explosives Act. Probably the most dangerous buildings are those used for some of the processes of gunpowder manufacture, such as granulating and pressing.

This Paper contains a description of the system of electric lighting, devised by the Author, adopted in some of the danger buildings of this class, at the Royal Gunpowder Factory, Waltham Abbey. At that factory, as is often the case, the powder buildings are spread over a considerable tract of low-lying ground, covered with trees, and intersected with numerous water-channels. The trees are valuable as screens in the cases of explosion, and the water furnishes both motive-power and safe means of transport. The buildings are light brick and wooden structures, partly surrounded, as a rule, by heavy traversers, designed to prevent an explosion from being communicated to the other buildings in their neighbourhood. Inside is the machinery. In "Dusty Buildings," when the machinery is at work the whole house is filled with a cloud of powder dust, which settles over everything, and, issuing from the doors and windows, covers the outside of the buildings and ground in the vicinity with a thin layer of explosive dust. In "Non-Dusty Buildings" there is comparatively little dust, though there is in most machine houses enough to cover the interior with a considerable sprinkling, but not enough to cause any appreciable quantity to settle outside the buildings. In both classes of buildings there is always a considerable quantity of powder undergoing the process of manufacture. The layer of powder-dust is sufficient to transmit ignition from any point within the limits of the "dusty area" where it may originate to the bulk of the powder in the building. The powder-dust, then, is the chief cause of the danger, since the least spark, or other cause of fire, occurring within the "dusty area" will cause an explosion of the whole of the powder in the building. The distinction between dusty and non-dusty houses has been long recognised, but having regard to the precautions necessary to make electric light safe, the Author slightly rearranged the classification according to the following definitions.

Dusty Houses are those in which the operation carried on produces such an amount of dust that the outside of the buildings and the ground in the neighbourhood may become covered with a layer of dust sufficient to communicate any fire occurring within the dusty region to the interior of the building. The following buildings at the Royal Gunpowder Factory are classed as dusty houses:—dusting houses; granulating houses; breaking-down houses; press houses.

The neighbourhood of a dusty house, namely, the whole area over which explosive dust may collect in sufficient quantity to be dangerous, has been called the "danger area." (See Home Office "Memorandum on Electric Lighting of Factories and Magazines for Explosives," December 31, 1891.) The boundary of this area is necessarily indefinite. It depends on the rate at which dust escapes from the building, the nature of the ground, the climate, and particularly on the length of the longest spell of dry weather which may be expected. At Waltham, the Author having consulted with the men of longest experience in the factory, fixed the boundary of the danger area at 50 yards from the nearest part of the building.

Non-dusty houses are those where there is never a sufficient amount of dust to cover the exterior of the building or the ground in the neighbourhood. The following buildings at the Royal Gunpowder Factory are classed as non-dusty houses:—incorporating mills; moulding houses; stoves; magazines.

I. DUSTY HOUSES.

If it were possible to keep all the electrical apparatus outside the "danger area," it would render the light perfectly safe. But it is clearly impracticable to light the interior of the building by lamps 50 yards from the nearest part of it. It is, however, possible to keep much of the apparatus outside this area, and to protect that part inside it in such a manner as to render it extremely safe.

The appliances which must be inside the "danger area" are, obviously, the lamp and the leads to it. Nothing else should be allowed inside the "danger area." And further, it is not necessary to take even the lamps inside the building, for sufficient light can quite well be obtained from lights outside the windows. Before describing the precautions which must be taken to make electric light safe, a brief list of the possible sources of danger is given:—

Sparks at any point within the "danger area" arising from:—(1) A broken wire; (2) Connection between positive and negative leads; (3) The blowing of a fuse; (4) The action of a lightning protector; (5) The opening of a switch; (6) The breakage of a lamp; (7) Lightning flash.

Heat.—(1) Of the lamp itself; (2) At the lamp-holder; (3) At any defective joint; (4) In the leads; (5) Owing to leakage or partial connection between positive and negative leads; (6) Owing to leakage to earth.

In order to avoid these dangers, the following precautions should be taken.

Sparks.—(1) The wires must be protected from breakage. If there are trees near, the wires must be taken underground, or they will be liable to be broken by falling branches; (2) The leads must be kept apart and well insulated, or else enclosed in a dust-proof case; (3, 4, 5) Fuses, lightning protectors, and switches must not be admitted inside the danger area; (6) The lamp must be protected; (7) Lightning protectors must be placed close outside the danger area, to prevent lightning being carried to the building by the wires.

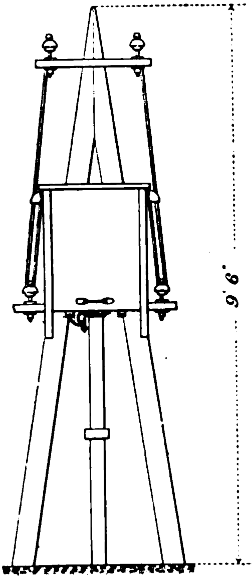
Heat.—(1) The lamp must be enclosed in an outer globe, of sufficient size to keep cool; (2) Suitable lamp-holders must be used, and they should be protected, like the lamp, from dust; (3) Joints in the wires should, if possible, be avoided; (4) The leads must be thoroughly protected by fuses; (5, 6) First-class insulation, suitable for the special conditions, should be used; great care must be taken in selecting the method of support for the wires.

With these conditions in view, the Author arranged the following system:—

The main leads, which are carried overhead, terminate at an

"A" post (*Fig. 1*), situated at least 50 yards from the building to be lighted, on which is fixed the switch-box, which contains all the fuses, switches, and lightning protectors used in connection with the building. The leads from this box, consisting of a pair of insulated wires to every lamp, are carried underground through iron pipes to the lamps. The lamps, which are all outside the buildings, are supported in front of the windows on lamp-posts of various forms, designed to suit the special circumstances of each case. The principle aimed at in the design of these is to provide a support for the lamp entirely independent of the building.

Fig. 1.

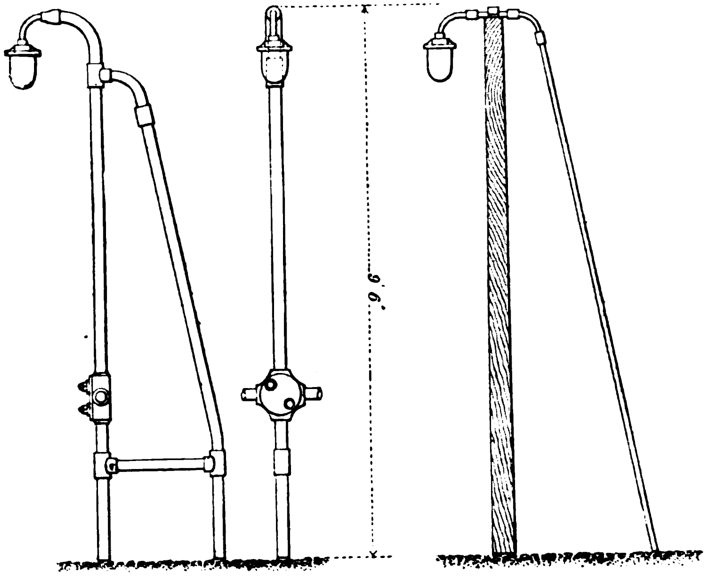


Figs. 2 show two forms of lamp-post. In all cases the wires are carried up to the lamp enclosed in an iron pipe, on the end of which the lamp is fixed. The pipe used is wrought-iron steam-pipe, with ordinary socket-joints, coated inside and out by Angus Smith's process. It starts at the switch-box, to which it is fastened by a flange, and runs underground to the building, where it branches, as required, to the various lamps. The size of the pipe is determined by the number of wires which it has to carry. The following Table shows the sizes which have been found most suitable for different numbers of lamps, each lamp having two wires.

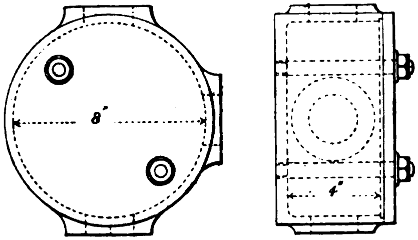
		Inches.
Lamps 1.	Inside diameter of pipe	1
„ 2.	„ „	1¼
„ 3, 4.	„ „	1½
„ 5, 6.	„ „	1¾
„ 7, 8.	„ „	2
„ 9, 10.	„ „	2¼

Cast-iron "drawing-in boxes" (two patterns of which are shown in *Figs. 3* and *4*) are placed at all the angles of the larger pipes, and the same box is used wherever the branches leave the main pipe, except that a smaller box is sufficient at the junction of the branches leading to single lamps. Drawing-in boxes are not necessary at all the bends of these smallest branches; but where they are not used, running joints are provided on both sides of the bends. The insertion of these boxes at the bends and branching

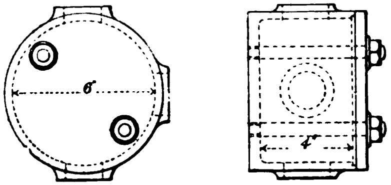
Figs. 2.



Figs. 3.



Figs. 4.



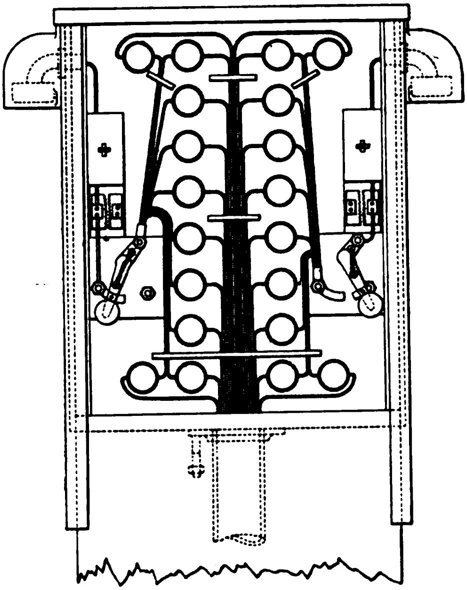
points greatly facilitates the drawing-in of the wires. No tees or elbows are allowed, on account of the sharp edges which are left inside these fittings. The sharp edges left on the insides of the pipes when they are cut are carefully removed before the pipes are fixed in their places. Those ends of the pipes which are screwed into the drawing-in boxes are belled out slightly so as not to catch the wires as they are drawn in. The joints are all made with red lead, including those round the lids of the drawing-in boxes.

The leads to the lamps are single No. 16 copper wires, insulated with vulcanised india-rubber and lead-covered, supplied by the India-rubber, Gutta-percha and Telegraphic Works Company, with a guaranteed insulation of 300 megohm miles. No joints are allowed in the leads; but as the wire is made in long lengths, this causes very little waste. The wires are drawn into the pipes, after they are completed, by means of soft spun-yarn ropes. The boxes, though small, give ample room to bend in the bight of the wires without kinks.

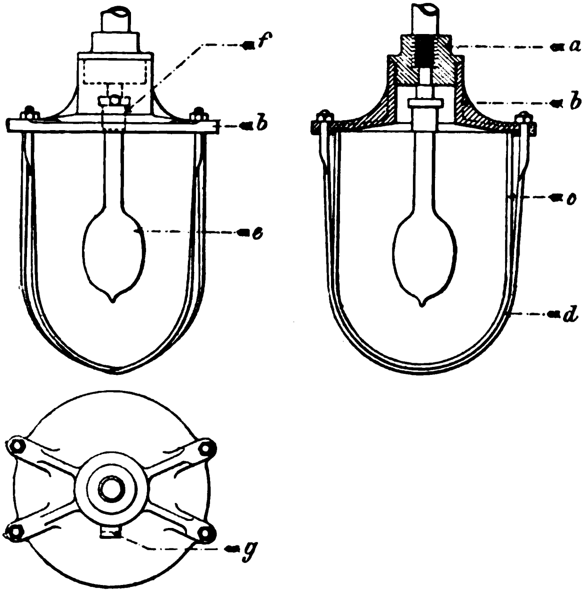
The switch-box is shown in *Fig. 5.* It is made of teak, of watertight construction, with either a wooden or a slate back on which the switches, &c., are fixed, and a sliding wooden front. The positive and negative leads enter the box through two Johnson and Phillips' fluid insulator "leading-in pipes," on opposite sides, and are joined to the two main fuses. The fuses are in turn connected through two lightning protectors to the two main switches. From the switches the leads divide and are joined to the two rows of single-lamp fuses. The lead-covered wires are connected to the other terminals of these fuses, and pass straight down into the iron pipe, the end of which is fixed to the bottom of the box. A wooden ring is fitted round the top end of the iron pipe to preserve the wires from getting cut, while they are being bent into position. The earth plates of the lightning protector are connected to the iron pipe.

The lamp (*Figs. 6*) is a modification of that invented by Colonel Watkin, in 1885. It consists of a cylindrical cast-iron piece *a*, tapped to screw on to the end of the iron pipe carrying the leads, and fitted with a nipple on to which the lamp-holder is screwed. The outside of the piece *a* is screwed, and fits into the cast-iron piece *b*, which forms a cover to the glass globe *c*, to which it is attached by the copper straps *d*. The joint between the glass and iron cover is made with an asbestos ring. A long-necked glow-lamp *e* is used, held in the holder *f*. The hole in the cover *b* is sufficiently large to allow the lamp *e* to pass easily through it. The globe is filled with water (with a small amount

Fig. 5.



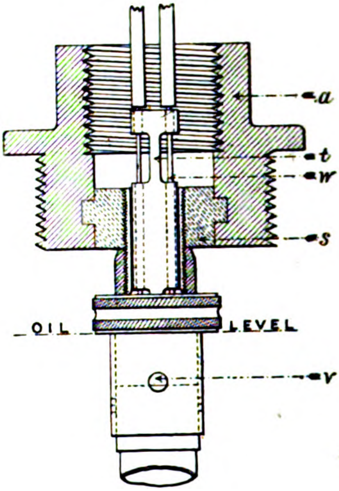
Figs. 6.



of glycerine to prevent its freezing), to within $\frac{3}{8}$ inch of the top. On the top of the water oil is poured up to the level of the filling-hole *g*, which is afterwards closed with a screw. A part of one side of the globe is silvered on the outside, and the rest of that half painted with white enamel.

The details of the method of attaching the lamp-holder, and leading in the wires, are shown in *Fig. 7*. The cast-iron piece *a* is recessed slightly near the bottom; and the nipple, which is tinned, is run in with sulphur *s*. Fitting loosely inside the nipple, and projecting above it, is the earthenware insulator *t*, which has two small holes formed in it, through which the bare wires *w* (the insulation having been removed) are threaded. It rests at the bottom, on the insulator, in the lamp-holder. Two small holes, *v*, are drilled in the sides of the lamp-holder, level with the top of the lamp, to allow the oil to enter and circulate. The glow-lamp is kept cool, and dust is prevented from settling on it by the water. The oil greatly reduces evaporation, and prevents the condensation of water on the lamp-cap and interior of the holder. This point is of great importance, since, if the plaster of Paris in the lamp-cap gets wet, heat is rapidly generated, and the metal contacts corrode by electro-chemical action. The oil also serves as an insulator and cooling agent round the lamp-holder,

Figs. 7.



and prevents dust settling there. It likewise seals the asbestos joint. The object of the sulphur is to insulate the lamp-holder. The earthenware insulator is to preserve the insulation on the wires from the decaying action of the oil. The expansion of the water and oil with any air they may contain, and also the expansion of the air enclosed in the top of the lamp, cause the oil to rise slightly when the lamp is hot. This takes place without the oil coming in contact with the rubber insulation. The shape of the insulator is designed to prevent the creeping up of oil by capillary action.

The Author tried many sorts of oil, such as rosin oil, rape oil, heavy hydro-carbon oils, and paraffin wax; but failed to find any which entirely prevented evaporation of water at 140° Fahrenheit. A heavy hydro-carbon machinery-oil was found sufficiently good; and by the special construction of the lamp the condensation of any moisture which does evaporate through the oil cannot take place on the wires, contacts, or lamp-cap.

To replace a glow-lamp, all that is necessary is to unscrew the cap *b* off the plug *a*, and carefully lower the globe, full of water and oil. The lamp can then be changed, and the globe replaced. The joint round the top of the globe is never broken; and there is no risk of spilling oil and water.

The Author made a few experiments to find out what size of globe was necessary in order that no part of it should get too hot when the lamp it contained was run continuously. The maximum allowable temperature, recommended by H.M. Inspector of Explosives, in the "Memorandum on Electric Lighting of Factories and Magazines for Explosives," is 140° Fahrenheit. Four globes of different sizes (*Figs. 8* next page) were tested; the results were as follows:—

Globe **A**, containing 8 ounces of water, boiled in two hours.
„ **B**, containing 130 ounces, attained a maximum temperature of 156° Fahrenheit.
„ **C**, 200 ounces attained a maximum temperature of 132° Fahrenheit.
„ **D**, 192 ounces attained a maximum temperature of 131° Fahrenheit.

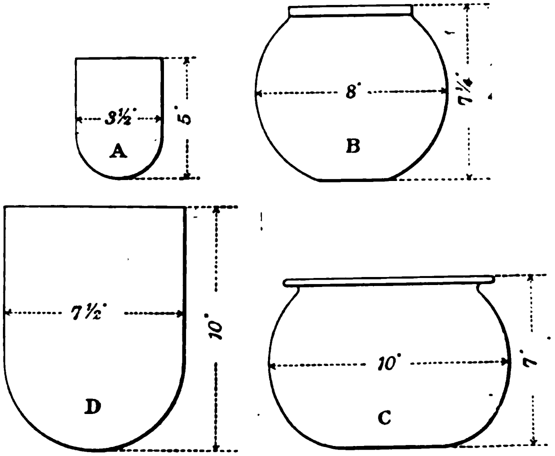
The glow-lamp in each case was absorbing 60 watts. The temperatures given are those of the surface layer of water in the globe; the temperature of the surrounding air being 60° Fahrenheit. Globe D is that adopted in the lamp above described.

A safety switching-off device is applied as follows: A weight is attached to the two main switches by a wire over a pulley so as to open the circuit. A pull-wire is run from the switches to some convenient point within reach from the building, by means of which the switches can be pulled on, raising the weight. In the event of any defect appearing in the lighting, the release of this wire will at once entirely disconnect the leads. If this wire, in course of time, breaks, the defect will show itself at once.

The Author believes that these arrangements fulfil all the conditions laid down. The following points may be specially noticed:—

The wires are entirely enclosed in dust-tight iron pipes the whole way from the switch-box to the lamps; that is, for the whole distance traversed within the danger area. The iron pipe will not only keep out the dust, but tend, in case of any short circuit, to develop it rapidly, and so to blow the fuse.

Figs. 8.



There are no joints in any of the wires. The wires, being lead-covered, are well protected against wet and iron rust. The drawing in of the wires is easily and quickly accomplished.

The fuses are set to blow at four amperes, well within the safe carrying capacity of the wires, and far above the regular working current. Thus there is perfect protection, and yet the fuses will be quite cold in ordinary work. The main fuses are only intended to act if lightning short-circuited the dynamo. They are also very large for the normal current.

The lamp globe, already described, affords complete protection from the danger of the lamp itself.

II. Non-Dusty Houses.

In lighting non-dusty houses, many of the sources of danger before enumerated do not exist.

Sparks.—There is no danger from sparks if they are kept clear of the building.

Heat.—There is no danger from heat if it is kept clear of the building. The following precautions are therefore sufficient:—

Sparks.—The wires need only be protected from breakage, or short-circuiting, in the immediate vicinity of the building. The fuses, &c., need only be kept a few feet off the building. The lamp, which is necessarily very near the building, should be protected from breakage. A lightning protector should be fixed on the main leads at a little distance from the building.

Heat.—The same precautions, as in the case of dusty houses, are necessary, but only in the immediate vicinity of the building.

The following description gives the particulars of the method of lighting non-dusty houses:—The main leads which are carried overhead terminate, as before, at an "A" post, situated at any convenient point near the building, on which is fixed the switch-box, containing, in this case, only the two main switches, main fuses, and lightning protectors. The leads (insulated) from this box are carried overhead again on posts round the building, at about 6 feet from the outside wall. The same lamps are used, fixed, as before, on posts outside the building, in front of the windows. The connection between the leads and lamps is made as follows:—One of the supporting posts for the overhead leads is fixed opposite every lamp; each of these posts carries a cast-iron fuse-box, containing two single lamp fuses; from this box a 1-inch iron pipe runs overhead to the lamp, a distance of about 6 feet. Branch wires are attached to the overhead leads, and carried into the fuse-box, and connected to the fuses. From the fuses, two wires are carried in the iron pipe to the lamp. *Figs. 9* show this fuse-box, and *Fig. 10* shows the general arrangement (see next page). By this arrangement the leads are kept sufficiently far from the house to be safe, in case of their breaking, while the branches to the lamps, which necessarily approach the house more nearly, are completely enclosed, and also protected from mechanical injury. There is a fuse on every lamp, as before.

In conclusion, a few words may be said about some other classes of Danger Buildings. At Waltham Abbey there are, besides the powder factory, a gun-cotton factory, and a cordite factory. In the gun-cotton factory, since there is no dust and hardly any gun-cotton in a sensitive state, no special precautions need be taken beyond those necessary in an ordinary house or factory, except

Figs. 9.

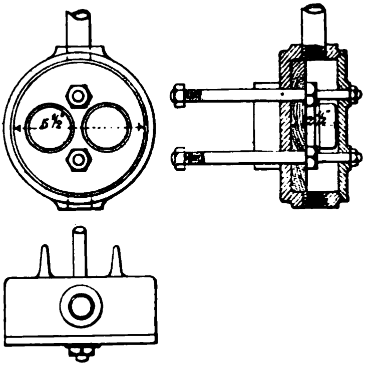
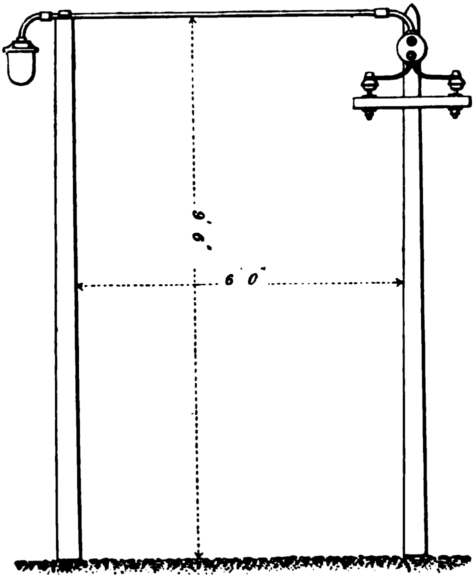


Fig. 10.



that the acid fumes should be specially guarded against. Such lamp-holders as Messrs. Woodhouse and Rawson's chemical holder may be used. In the cordite factory, as there is no dust, the lamps may be taken inside the houses, but should be protected by suitable globes. Also the leads should be entirely enclosed. The fuses, &c., should be outside the buildings. A modification of the first system described may be used, carrying the pipes inside the buildings. The dry gun-cotton buildings should be treated like dusty gunpowder-houses.

The illustrations have been reduced and engraved from the tracings which accompanied the Paper.

OBITUARY.

ROBERT HARRIS, the eldest son of the late Mr. Robert Harris, of Feltham, Middlesex, was born on the 14th of September, 1835. When between sixteen and seventeen years of age he became a pupil of the late Mr. Alexander Wright, the Engineer to the Western Gas Light Company, and was engaged at the Company's works at Kensal Green, and upon similar works at Luton, Penzance, and other towns. In January, 1859, on the death of Mr. Wright, he was appointed Engineer of the gasworks at Bow Common, then the property of the Great Central Gas Company. When that Company was amalgamated with the Gas Light and Coke Company, Mr. Harris was retained as Engineer of the Bow Works, and appointed "Regulating" Engineer of the Eastern Division of the latter. He also acted for some years as Consulting Engineer to the East Barnet Gas Company. In 1884 he left Bow and entered the Company's station in Goswell Road as General Distributing Engineer, which post, however, he was obliged to resign in 1889 on account of ill-health.

Mr. Harris died on the 5th of April, 1892, from a paralytic seizure. As a gas engineer he possessed considerable ability; and his simplicity of character and kindness of heart gained for him universal respect and affection. He was an active member of "The Gas Institute," and served as President in the year 1884. Mr. Harris was elected a Member of the Institution on the 4th of March, 1873.

JOHN HEMPHILL MORANT, son of the late Captain George Morant of the Grenadier Guards and of Shirley House, Carrickmacross, Ireland, was born on the 29th of April, 1847. After being educated at Cheltenham College, where he obtained several prizes, he was articled in 1866 for four years to Mr. James Barton of Dundalk. On the expiration of his pupilage he acted for Mr. Barton as Resident Engineer on the construction of the Dundalk and Greenore Railway until May, 1872, when he proceeded to Brazil as First Assistant Engineer on one of the four staffs organised to survey a projected line of railway from the harbour of Paranagua, on the Atlantic seaboard of the Province of Paraná, to Miranda in the Province of Matto Grosso on the borders of Bolivia, a distance of about 1,300 miles. Among the concessionaires from the Brazilian Government for this line were the late Viscount Mauá and the late Captain Christian Palm of the Swedish Royal Engineers. The Consulting Engineers were Messrs. Brunlees and McKerrow, and Captain Palm was Engineer-in-Chief until his death, when he was succeeded by Mr. William Lloyd, and, during the absence of the latter, by Mr. H. Edgell Hunt.

On the completion of the work of his own staff, which included the survey of some 260 kilometres through difficult and unexplored country, Mr. Morant joined a supplementary staff formed to assist the second staff, whose work lay yet farther in the interior. He then went to Rio de Janeiro to prepare the plans, after the presentation of which to the Government in June, 1874, he returned to England. The great difficulties encountered in carrying out these surveys through an unknown country, peopled for the most part by tribes of Indians, with impenetrable forests, tropical heat, insufficient food and accommodation, and every possible torment in the shape of mosquitoes and other insects, demanded endurance, pluck, and self-denial, and Mr. Morant showed that he possessed the qualities necessary to meet and overcome all obstacles. It is related that on one occasion, when a sudden rising at night of the Rio Ivahy flooded the camp, his bed floated in the direction of the river on the two empty barrels which supported it; on awaking he calmly sat up and lighted a pipe before proceeding to more energetic measures.

In 1887 Mr. Morant was appointed Acting Engineer to the Irish Lights Commissioners, which post, however, he resigned in May of the following year, being presented by the Commissioners with the sum of £300 on his retirement. In 1879 he again proceeded to Brazil as Assistant Resident Engineer on the construction of the Natal and Nova Cruz Railway, and in the following year became Chief Engineer for the contractors, which position he held until 1884, when he was appointed Chief Engineer to the Central Sugar Factories of Brazil. In 1885 he returned to the service of the Natal and Nova Cruz Railway Company as Resident Engineer and Manager, which post he occupied at the time of his death, from the effects of sunstroke, on the 1st of June, 1892.

Mr. Morant was a man of high character and of more than ordinary ability as an engineer. His generous and amiable disposition won the esteem and respect of his brother officers and of all who came into immediate relation with him. In 1888 he received the Brazilian decoration of the Imperial Order of the Rose as a recognition of his services in preparing the first map of the Province of Rio Grande do Norte. In April, 1885, he married a daughter of Mr. Wells Hood, of Pernambuco, leaving her a widow with one child. Mr. Morant was elected an Associate of the Institution on the 11th of January, 1876, and was transferred to the class of Associate Member on its creation in December, 1878, and to that of Member on the 11th of November, 1890.

WILLIAM SMITH, son of the late Mr. J. H. Smith, was born at Elphin, county Roscommon, Ireland, on the 23rd of June, 1823. He was educated at Elphin Diocesan School and at Trinity College, Dublin, where he graduated as Bachelor of Arts in 1844. In the following year he entered the service of the Board of Works in Ireland, in which he remained until 1852, being employed for the first half of that time as an Assistant Engineer on the Shannon Navigation Works, and for the latter half as an Inspector of Drainage and other works under the Irish Lands Improvement Acts. He then acted for nearly two years as Manager of the Brighton Waterworks.

In February, 1855, Mr. Smith was appointed an Assistant Engineer in the Public Works Department of the Government of India. He was posted to the office in Calcutta of the Civil Architect of the Presidency Division, and in the following year was placed in charge of the survey and of the preparation of designs and estimates for bridging and metalling the Jessore Road. On the completion of that work, he acted for a short time in 1857 as Civil Architect, and was then appointed Executive Engineer of the Burdwan Division, which included the construction of the Damooda and Adji embankments and of civil buildings in the Burdwan and Bancoorah districts. He held that post for five years, acting for several months in 1860 as Superintending Engineer of the Burdwan Circle. In 1862 he was posted to the Presidency Division as Civil Architect, and two years later was promoted to the rank of Superintending Engineer, transferred to the South Eastern Circle, and appointed President of the "Bengal Cyclone Relief Committee," for his services in connection with which he received the thanks of the Government of Bengal.

In July, 1865, Mr. Smith accepted, with the consent of the

Government, the post of Chief Engineer to the Waterworks of the Calcutta Municipality, and proceeded to England to prepare plans and specifications, and to arrange for the construction of the works by contract. Plans had been prepared a year before by the late Mr. William Clark, whom ill-health had compelled to resign the appointment of Engineer to the Municipality. Mr. Clark's project, however, was considerably modified by Mr. Smith, and the works were successfully completed early in 1870, when he reverted to his former appointment of Superintending Engineer of the South Eastern Circle. Two years later he was transferred to the charge of the Presidency Circle, and was nominated a Fellow of the Calcutta University, and in 1873 a Commissioner of the Port of Calcutta. In September, 1875, he was deputed to Simla to act on a Committee for the improvement of the sanitation of that station, and in the following November was placed in charge of the Northern Circle, Bengal.

In the autumn of 1876 Mr. Smith's services were placed at the disposal of the Government of India for employment as Superintending Engineer of the Simla Imperial Circle, in which capacity he designed and carried out a scheme of water-supply and drainage for the town of Simla. He retained charge of this Circle until its abolition at the end of 1878, when he was re-appointed Superintending Engineer of the Northern Circle. In the following October he was obliged to retire from the Public Works Department under the operation of a resolution which, consequent on the necessity for curtailing expenditure, ordered a large reduction in establishment, and directed the retirement of civil officers who had attained the age of fifty-five years. He received from the Lieutenant-Governor of Bengal a service certificate couched in extremely complimentary terms.

On his retirement from Government service, Mr. Smith was appointed Consulting Engineer to the Rajah of Cooch Behar. Some time after his return to England he accepted the post of Secretary to the "London Sanitary Protection Association," which he held until his death on the 18th of May 1892, in the sixty-ninth year of his age. Mr. Smith was an engineer of considerable ability, and his high character and genial disposition made him popular amongst a wide circle of friends. He was elected a Member of the Institution on the 15th of May, 1866.

ALEXANDER WILLIAM CONQUEST, son of the late Mr. William Conquest, for many years Secretary to Sir Joseph Bazalgette at the Metropolitan Board of Works, was born on the 17th of September, 1848. After being educated at a private school at Shoreham in Sussex, he was articled in 1864 to Mr. Edmund Cooper, then one of the Assistant Engineers under the Metropolitan Board of Works,' and was employed for about five years on the works of the Thames Embankment from Waterloo Bridge to Blackfriars, and on the Northern Low-level Sewer from Tower Hill through the City. He was next engaged until 1874 under Mr. Thomas Lovick, then an Assistant Engineer to the Board, on the construction of the Western Pumping Station, and on the works of the Chelsea Embankment. From December, 1874, to March, 1875, he acted temporarily as Surveyor to the Chelsea Vestry, and during that time designed and carried out some important lines of sewers in different parts of the parish. From May to October of the same year he performed the duties of Surveyor to the City of Norwich, during the absence, from ill-health, of Mr. Christopher Thwaites. During that year, also under Sir Joseph Bazalgette, he took the levels and prepared the Parliamentary plans for the diversion of a portion of the West Kent main intercepting-sewer.

In November, 1875, Mr. Conquest was elected, out of one hundred and seventy-eight candidates, Engineer and Surveyor to the Borough of Ramsgate. During the time he held that office he constructed a sea-wall for the protection of the West Cliff, several carriage- and footway-pavements, and extensive drainage works; he also prepared plans for the interception of the sewage of Broadstairs, St. Peters, Ramsgate and St. Lawrence. On leaving Ramsgate in 1880 to take up the post of Engineer to the Borough of Folkestone, Mr. Conquest was presented with a handsome clock by the employees of the Corporation, and with an address and a purse of fifty guineas by some of the inhabitants. During his connection with Folkestone, which was destined to last for the remainder of his life, Mr. Conquest carried out many improvements, amongst which may be mentioned the laying out of Radnor Park, the paving with wood of the principal streets and the making of new main roads, the construction of a fish market, and the extension of the system of sewerage throughout the borough. He also designed and carried out several additions and alterations to the Town Hall. He was Superintendent of the

Borough Fire Brigade, and during his term of office a new fire station was built, and improved means of communication were established between the headquarters and the firemen's residences. Mr. Conquest was very energetic and thorough in the discharge of his duties, and invariably insisted upon having all work with which he had to do carried out in the best possible manner. He enjoyed the entire confidence of the various public bodies by whom he had been employed.

Mr. Conquest died from blood-poisoning on the 5th of February, 1892. He had recently recovered from an attack of influenza, but went out too soon and caught a chill. On reaching home he placed his feet near the fire, causing a blister to form on one of the toes. Unfortunately, the dye from his sock entered the wound and caused blood-poisoning; mortification set in, and it was found necessary to amputate the leg below the knee, an operation which he survived only two days. Mr. Conquest was elected an Associate Member of the Institution on the 4th of March, 1879.

ALFRED JAMES CORRY, youngest son of Mr. Edward Corry, was born at Kensington on the 13th of January, 1858. He was educated at the Oratory School at Edgbaston, near Birmingham, under the late Dr. (afterwards Cardinal) Newman, and at Liége in Belgium. On returning to England in 1874 he studied engineering in the Applied Sciences Department at King's College, London, and subsequently spent some months at the ironworks of Messrs. Bower at St. Neots in Huntingdonshire. In 1876 he was articled to the late Mr. T. W. Rumble, then Chief Engineer to the Southwark and Vauxhall Water Company. On the expiration of his pupilage he remained in the service of the Company as an Assistant Engineer, and subsequently acted as Resident Engineer on new works at Streatham, and superintended the erection of a shaft at Battersea. After leaving the Southwark and Vauxhall Water Company, he entered the works of the Maxim-Nordenfelt Gun and Ammunition Company at Erith, where he was employed chiefly in designing labour-saving machinery. He remained at Erith until he became associated with Captain McEvoy in the conduct of an electrical and submarine mining business in Westminster, in which he was engaged at the time of his death on the 4th of April, 1892. Mr. Corry was an accomplished draughtsman, with a capacity for readily grasping engineering details. Energetic in temperament and generous in disposition, he secured many warm and devoted friends. He was elected an Associate Member of the Institution on the 1st of May, 1883.

JOSEPH PRENDERGAST COY, younger son of Mr. John Coy, of Leicester, was born on the 30th of May, 1857. At the age of eighteen he was placed as a pupil in the office of Mr. John Waugh, Civil Engineer, of Bradford, where he was engaged in preparing designs for gasworks, mill-engines, and other machinery. In August, 1875, he was sent by Mr. Waugh for a course of practical training to the shops of Messrs. W. and J. Yates, engineers and millwrights, of Blackburn. There he remained until April, 1876, when he left to prepare for the entrance examination of the Royal Indian Engineering College at Cooper's Hill. He went through the three years' course at Coopers' Hill, where he was known as a diligent and successful student, modest and retiring, and he passed out sixth in July, 1879, a year noted at the college for severity of competition.

After ten months' preliminary training at the works of Messrs. Handyside and Co., Derby, where he was principally engaged on designs for bridges and roofs, Mr. Coy took up the appointment of Assistant Engineer in the Public Works Department of the Government of India. He joined the Northern Drainage and Embankment Division at Calcutta in November, 1880, and was chiefly occupied in levelling and in preparing estimates for remodelling the Sunderbund tidal embankments. In March, 1882, he was placed in charge of the irrigation of 85,000 acres under the Midnapur Weir, and of the maintenance of 20 miles of canal, and 200 miles of distributary channels. Between the years 1883–87, he was engaged on the Sone Canal system in Bengal, when, for about two years, he had charge of the Buxar subdivision, his duties being to distribute the water from the canals to the cultivators, to keep the canals and distributaries within his subdivision in proper repair, and to carry out the new works, *e.g.*, distributaries, drainage-channels, buildings, &c., required to develop the resources of the canals. In July 1885, Mr. Coy took charge of the Dehri Division of the same circle. This division comprised, chiefly, the head-works—including the weir or anicut, over 2 miles in length, with the head-sluices of the two great systems, known as the Main Eastern and the Main Western, which are supplied from the Weir-pool—the Dehri workshops—kept up for the manufacture of dredging-plant and other requirements of the canals—the large fleet of dredgers, constantly engaged in removing silt from the canal-heads, and the Dehri quarries, where the stone for any works in progress is supplied. While he was at Dehri it was decided to rebuild the piers of the weir on a remodelled design, with new and stronger under-sluices in place of the old ones. This work was satisfactorily carried out. In April, 1888, he went to England on furlough.

On his return to India in November, 1889, Mr. Coy was employed on irrigation works in Orissa, where, in addition to duties similar to those he had performed on the Sone Canals, he was charged with the construction of embankments and other works. At the time of his death, which took place suddenly on the 5th of March, 1892, at Acquapada, Orissa, he held the rank of Executive Engineer, 3rd-Grade. Mr. Coy—who was regarded as an able and painstaking officer—was elected an Associate Member of the Institution on the 6th of February, 1883.

THOMAS DUNCAN, son of the late Mr. J. Duncan, of Aberdeen, was born on the 30th of June, 1855, and was educated at the Grammar School and the University of that city. Before, however, he had completed the usual academic course, he expressed a strong desire to follow engineering, and was therefore articled, in April 1874, to Messrs. J. F. Beattie and Son (afterwards Messrs. Walker and Beattie), Civil Engineers and Land Surveyors at Aberdeen. On the expiration of his pupilage, in April 1879, he was retained by the firm as Chief Assistant, which post he occupied for about eight years. During that time he was engaged in the design and superintendence of roads, sewage and water-supply works, the drainage and reclamation of land, and in preparing Parliamentary plans in connection with railways. In 1880 he went for the firm to South Uist and Bembecula, to make reports and plans of improvements proposed for those islands, and to institute a general re-arrangement of the land and crofts.

Mr. Duncan entered into partnership, in 1887, with Mr. William Dalton Ironside, under the style of Duncan and Ironside, Engineers and Surveyors, at Aberdeen. The firm carried out several small waterworks and roads in the country; but the partnership was dissolved in 1891, when Mr. Duncan joined Mr. Walker, and the firm became Messrs. Walker and Duncan. He was, however, suffering from a painful internal complaint, from which he never recovered. In the autumn of that year he was confined to the house, and on the 18th of March, 1892, he died, at the early age of thirty-seven. Mr. Duncan was elected an Associate Member of the Institution on the 4th of December, 1883.

FRANCIS GILLHAM was born on the 13th of May, 1853. After going through the engineering course at the Hartley Institution, Southampton, he was articled in January, 1873, for two years, to Mr. William Dennis, of Westminster. On the expiration of his pupilage he abandoned engineering for six or seven years and followed other pursuits; but in January, 1882, he went to Venezeula as an Assistant Engineer on the La Guaira and Caracas Railway. He acted in that capacity until September 1883, from which time until the following February he was in sole charge, for the contractors, of the same railway. He was also in charge from November, 1883, to the following May, of the construction of a short railway for the Venezuelan Government, and from December 1884 to May 1885 was Resident Engineer on the San Domingo Harbour Works. In June of the same year he entered the service of Messrs. James Livesey and Son, with whom he remained for nearly three years. Mr. Gillham's work for Messrs. James Livesey and Son was of a varied nature. In August 1885 he reported on the then existing works of the Costa Rica Railway, and what was necessary to be done to complete the line. At the beginning of the following year he returned to England, and in July 1886 went to Asia Minor to report on a line from Haidar to Ismid. In October of the same year he proceeded to Trinidad, to report on the proposed railway and pier for that island. Thence he went to Venezuela, where he reported on the La Guaira and Caracas Railway, and on the Venezuela Central Railway, which latter line was then in course of construction. He next examined and reported on the Puerto and Cabello and Valencia Railway, also in course of construction. Whilst in that part of the country he went to Tucacas, to report on the line existing there, and on its proposed extension to Barquisimeto. In January 1887 he returned to Costa Rica, where he had to report on the damage done to the bridges on the Costa Rica Railway by recent floods, and on the works of the line generally. After a short visit to England, he went back to Costa Rica in June 1887, to take up the appointment of Resident Engineer of the railway. In the following November he resigned that post and returned to England, from which time his connection with the firm of Messrs. James Livesey and Son ceased.

At the beginning of 1888 Mr. Gillham was engaged by Messrs. J. E. Meiggs and Son, the contractors, to report on the Porto Rico Railway, but, as the climate of South America was beginning to affect his health, he was obliged to return home in the following April. In May of the same year he became the representative in England of Messrs. Delfin Sanchez and Co., contractors for the Interoceanic Railway of Mexico, of which the Mexican Government had appointed him a Director. Mr. Gillham was destined to occupy that post for the remainder of his life. He was responsible, amongst other things, for the purchase of the whole of the materials required by the Contractors for the carrying out of the contracts in Mexico, for the arrangement of all matters with the company and the Chief Engineers in London, Messrs. James Livesey and Co., for the engagement of the whole of the staff sent out from England, and for the proper conduct of the London office, which was the headquarters of the firm. It was understood, also, that at any time he might be called to Mexico to take charge of the contract, which at the beginning of 1889 included 500 miles of railway, with probable extensions within a short time of some 300 or 400 miles more. As a matter of fact, Messrs. Delfin Sanchez and Co. offered him originally the post of Chief Contractor's Engineer in Mexico, which he declined, as his health had suffered from his residence in Costa Rica.

An acute attack of remittent or malarial fever was the cause of Mr. Gillham's untimely death, which took place at Ryde's Hill, Guildford, on the 18th of March, 1892. He was a man of high character, and possessed considerable ability as an engineer—ability, the value of which was enhanced by the zeal he always displayed in looking after the interests of his employers. Mr. Gillham was elected an Associate Member of the Institution on the 5th of March, 1889.

JAMES JOHN TALMAN was born on the 11th of July, 1848. At the age of eighteen he was apprenticed to Mr. J. W. Wilson for three years, during the latter part of which time he was occupied on works for the Star Cross Pier and Oyster Company, and for the Herne, Hampton and Reculver Oyster Fishery Company. After the expiration of his pupilage, he was employed by Mr. Wilson in 1870 and 1871 in preparing Parliamentary plans for promenade piers at St. Leonards and at Broadstairs. He then for several years carried on the business of a shipowner, personally designing and superintending the building of vessels, as well as their alteration and repair. He was also occasionally engaged during that time in surveying, building, and other work connected with engineering.

In April, 1880, Mr. Talman obtained the appointment of Colonial Engineer and Surveyor at Lagos, on the West Coast of Africa, which post, however, he resigned towards the end of 1882, when he returned to England, and resided for a time at Broadstairs. At the beginning of 1884 he removed to Harbledown, near Canterbury, and subsequently took a prominent part in connection with the Canterbury Boundary Extension Inquiry. For the last few years of his life he had an office in Westminster, where he practised as a Civil Engineer. Mr. Talman died suddenly on the 3rd of March, 1892, from a gunshot wound received while out shooting at Grove Ferry, in the neighbourhood of Canterbury. He was elected an Associate Member of the Institution on the 6th of December, 1881.

HENRY WOOLCOCK, son of the late Mr. Henry Woolcock, mining engineer, was born at Illogan, in Cornwall, on the 28th of February, 1842. At the age of thirteen he became a pupil and assistant to his father, part of his duties being to assist in taking down and in erecting large pumping-engines and other machinery. From 1859 to 1861 he superintended, under the late Mr. William Richards, of Redruth, the erection of pumping and other machinery, and the laying out of the works at the New Wheal Hender Mines. He then left Cornwall, and for the next two years was Assistant Manager of the Greenside Lead Mines and Smelting Works, in Westmoreland, owned by Messrs. G. Head and Partners. There he had the supervision of all the surface and underground hydraulic machinery for pumping, winding, crushing and cleaning the lead-ore, of the reservoirs and watercourses, and of the smelting works and tramways. In 1863 he was promoted to the post of Engineer and General Manager, and for the next three years was occupied in designing and in laying out the reservoir, watercourses, hydraulic machinery and plant for working the Hartsop Hall

Mines and the Myres Head Mines. Mr. Woolcock's next appointment, which he held from 1866 to 1873, was that of Engineer and General Manager to Messrs. Hannay and Co., at their mines and collieries in Lancashire, Cumberland and Scotland. During that time he designed and laid out all the machinery and works connected with the mines and collieries owned by the firm, and also advised as to the machinery and plant for their ironworks at Blochairn.

In 1873 Mr. Woolcock started in business on his own account at Whitehaven as a Civil and Mining Engineer. He rapidly acquired an extensive practice, in addition to which he acted as Consulting Engineer to the Dalmellington Iron Company, the Eskett Iron Ore Company, Messrs. Fletcher and Hodgetts, the Asby and Wythemoor Colliery Companies, the Wyndham Mining Company, and to the Earl of Dundonald in connection with mineral properties in Scotland. For the Wyndham Mining Company he sank a pit through beds of quicksand, gravel and boulders, varying from 4 feet to 15 feet in thickness, to a depth of nearly 100 feet. At a depth of about 90 feet the machinery was overpowered, and, as there was no room to increase the pumping-capacity, Mr. Woolcock was obliged to suspend work for a time. He then sank a second larger pit at a little distance, and this was successfully completed to a depth of nearly 360 feet. The quantity of water pumped from this shaft during the sinking was over 1,200 gallons per minute. Mr. Woolcock was also Consulting Mining Engineer to the London and North Western and to the Furness Joint Railways, in the North Lancashire and Cumberland districts, to the Falcon Mining Company at Egremont, and to the Askam and Mouzell, and the Millom and Askam Companies for their hematite mines. He had, too, considerable experience in Parliamentary work, and in arbitration cases.

In May, 1889, Mr. Woolcock went to South America to report on the mineral deposits on the lower reaches of the Orinoco. There he suffered great hardships, which, added to his neglect of the usual precautions necessary to be taken by Europeans in the tropics against malarial fever, considerably impaired his naturally strong constitution. He died suddenly on the 16th of February, 1892, from failure of the heart's action induced by influenza, at the age of fifty. Mr. Woolcock was kind and genial in manner, and was much esteemed in the district in which he was so well known. He was elected an Associate Member of the Institution on the 13th of January, 1880.

THOMAS HENRY EAGLES was born on the 31st of May, 1845. His professional career was commenced in August 1859, in the office of his uncle, Mr. Henry Dangerfield, then Borough Surveyor of Cheltenham, but on the retirement of Mr. Dangerfield, on account of ill-health, Mr. Eagles, in 1862, entered the office of Mr. R. Reynolds Rowe, then Borough Surveyor of Cambridge, under whom he served for five years as an articled pupil. In 1867 he matriculated at Queen's College, Cambridge, and graduated in mathematical honours in 1871, being placed 27th Wrangler; he proceeded to the degree of M.A. in 1874.

During the years 1871–72 Mr. Eagles was assistant to Mr. W. S. Cross, Architect and Surveyor to the London estates of the Duke of Bedford, and while there passed the qualifying examination for a District Surveyorship under the Metropolitan Building Act. In September 1872 he was appointed Instructor in Architectural Drawing at the Royal Indian Engineering College, Cooper's Hill, and shortly afterwards became, in addition, Lecturer in Architecture and Estimating, and in 1879 Instructor in Geometrical Drawing on the retirement of Major (then Captain) Clarke, R.E., C.M.G., which appointments he retained until the time of his death. With his academic work he also continued the practice of his profession as occasion allowed. The lecture-rooms, laboratories, and further extensions of the college required from time to time, with other buildings in the neighbourhood, were designed and carried out by him.

Zealous and earnest in his college and professional engagements, Mr. Eagles was not less ardent in taking part in vigorous sports and athletic pursuits. When at Cambridge he was captain of his College Boat Club, and during his term in a London office he joined the Royal Naval Artillery Volunteers. Soon after his appointment to the Royal Indian Engineering College he became a Lieutenant, and subsequently Captain, of the Volunteer Company of the Berkshire Regiment formed by the college students. He qualified himself for his position by passing with honours, in 1881, the examination for volunteer officers in tactics. He took the greatest interest in the discipline and efficiency of his company, and was proud of the high reputation it held in the regiment. In the rifle matches he was always a member of the team, and was one of its best shots. He also took a leading part for many years in the management of the College Boat Club, and in training the crews.

Mr. Eagles closely identified himself with all that promoted the welfare of the students of the college, and by his professional abilities and attainments, as well as by the interest and energy he displayed in their physical pursuits, he enjoyed the greatest popularity and respect. His clear and incisive intellect enabled him to grasp the details and master the essential points of any matter which claimed his attention. It may truly be said that it was within his power to achieve success in any walk of life to which he chose to apply himself. As a volunteer officer he possessed the true military spirit of a born soldier. As a mathematician he could, no doubt, have risen to considerable eminence, as is, indeed, evidenced by the two books of which he was the author, the one on the "Constructive Geometry of Plane Curves," the other on "Descriptive Geometry," published respectively in 1885 and 1890.

During the many years of service Mr. Eagles had rendered to the college, he had won the high opinion of all connected with it, and was admittedly one of the most valued and useful members of the staff. The loss to the college by his untimely death will be deeply felt, not only by the present, but by many of the past students scattered over India and other distant lands.

Premonitory symptoms of the illness which proved fatal were apparent during the autumn of 1891, but he continued his work throughout the term, and his medical advisers thought there could then be nothing seriously wrong. In December, however, he sought further medical opinion, which was to the effect that he was suffering from aneurism of the heart. Absolute and entire rest was prescribed, and Mr. Eagles was relieved of all college duties; but he gradually lost strength, and died on the 27th of March, 1892. He was buried with military honours at Englefield Green, being followed to the grave by the Students' Volunteer Company, by the President and Staff of the college, and by many friends.

Mr. Eagles was elected an Associate in 1871, and a Fellow in 1881, of the Royal Institute of British Architects, and in 1891 was appointed a member of the Board of Examiners in Architecture. For many years he was an Assistant Examiner, and subsequently one of the Chief Examiners in Geometrical Drawing to the Department of Science and Art, and was frequently employed on similar work by the Royal Military Academy and by the Civil Service Commissioners. Mr. Eagles was elected an Associate of the Institution on the 16th of January, 1877.

JOHN FREDERIC MAIN, son of the late Mr. David Main, Civil Engineer, was born at Greencastle, in the island of Jamaica, on the 7th of July, 1854. Taken as a child to England, he received his early education at the Southern Division Grammar School, at Southsea. In October, 1872, he entered Trinity College, Cambridge, where he won a mathematical scholarship, and in the Tripos of 1876 was ranked Tenth Wrangler. He was President of the Cambridge Union Society in the Easter term of that year. In January, 1872, he had matriculated seventh in honours at the University of London, where he subsequently passed the first and second examinations for the degree of Bachelor of Science, and in June, 1877, obtained that of Doctor of Science, the special subjects taken being Light, Heat and Acoustics treated mathematically, he being then barely twenty-three years of age. In the following October he was appointed Lecturer in Mathematics and Applied Mechanics at University College, Bristol. With characteristic energy, he sought additional qualifications for this post by obtaining practical experience during three summer vacations, which he spent respectively in carrying on experimental work at the Cavendish Laboratory, Cambridge, in practical work at Professor Stuart's workshops, in the same place, and in the drawing office in New York, of Mr. Thomas Main, who subsequently became Manager of the works of Messrs. John Roach and Sons, at Chester, Pennsylvania.

Dr. Main's connection with University College, Bristol, lasted for four years, and proved one of importance in the history of that Institution. In the first year, his gifts as a lecturer and teacher were so signally demonstrated, that the Council of the College entrusted to him the arduous task of founding and organizing the School of Engineering, which he had induced them to try to establish, and appointed him Professor of Mathematics, Applied Mechanics and Engineering—an office he held for the following three years. Chiefly owing to his exertions, the newly-founded school gathered strength, and soon grew into one of the most promising departments of the College. The system adopted was that suggested some years before by the late Professor Rankine, and subsequently formulated by Dr. Main's predecessor at Bristol, Mr. W. R. Bousfield, viz., a combined practical and theoretical training, to consist of the pursuit of theoretical studies at the College during the winter months, and of practical work in engineering shops during the summer months. The course of Mechanical Engineering was arranged to extend over three years, and various manufacturing engineers in the neighbourhood consented to receive students of the College into their workshops and offices as articled pupils. To successfully carry out this plan required no ordinary energy and work; those who owe their training to him could have had little knowledge of the difficulties of the task Dr. Main had undertaken; yet, with all the labour this imposed, he could find time to give several "Gilchrist" lectures in Bristol and the surrounding neighbourhood, and for the study of astronomy. But hard work began, after a time, to tell on a constitution which had never been robust, and in 1881 he decided to apply for the post of Assistant Professor of Applied Mechanics at the Normal School of Science (now the Royal College of Science), South Kensington, the duties of which were lighter than those of his Bristol professorship. Unhappily, Dr. Main's tenure of this post proved but brief. Before he had been a year at South Kensington his health gave way, and although he struggled manfully against a severe pulmonary attack, it made such inroads on his strength as to force him to leave England in the spring of 1883, and to make his home for a time at Davos, in Switzerland. He benefited so much by his stay in the High Alps that there was for a time great hope of his complete recovery, and his post at South Kensington was kept open for more than a year. It was a delusive prospect, however; his health, though greatly improved, was never, during his residence in Switzerland, so far re-established as to allow him to revisit England for longer than a few weeks; and even in Switzerland he was at least once brought very near death by acute illness. It was his fate to remain in that country until late in 1887. In the last months of his residence, he contemplated, and actually made some progress towards, setting up at St. Moritz a telescope of considerable power, which Sir Howard Grubb was making for him. He also made some observations and experiments in the Engadine on the viscosity of ice, an account of which was published in the Proceedings of the Royal Society.[1]

In October, 1887, his health having to a certain extent improved, Dr. Main determined to go to Colorado, in the hope of regaining a still larger measure of strength. After a short stay in England, he settled in Denver at the beginning of the following year. There his expectations seemed more than realized, something of his former vigour, and a considerable amount of his old energy, were restored. Again his life became busy; he gave lectures, edited and wrote for a local newspaper, and frequently travelled great distances. In partnership with an Englishman, Mr. Thomas J. Pulling, he entered into business in connection with investments and mortgages of town property in Denver. So successful were they, that towards the end of 1890 they decided to start a limited company under the style of the Denver Banking and Investment Corporation, of which he and Mr. Pulling became managers. More than half of the capital was secured in England, and when, in the spring of 1891, Dr. Main visited this country, he was apparently in excellent health. In the following December, however, symptoms of paralysis began to manifest themselves, and though for a time these appeared to have yielded to treatment, and even to have been entirely subdued, they were revived in a more malignant form by an attack of scarlet fever. After a brief rally, he died on the 10th of May, 1892, at Denver, at the early age of thirty-seven.

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[1] Proceedings Royal Society, vol. xlii. pp. 329, 491.

Of the personal character of Dr. Main, it is impossible to speak too highly, without using words which would sound like exaggeration. Possessed of intellectual powers of a high order—a fact which was strikingly supported by his personal appearance—he at the same time had only a frail constitution, and hence never attained that position in the world which his friends anticipated for him, and which in their opinion he was so well fitted to occupy. Dr. Main was elected an Associate of the Institution on the 6th of December, 1881.

DAVID REID, born on the 11th of January, 1841, at Tilliery near Milnathort, Kinross-shire, was the youngest son of the late Mr. Robert Reid, who, with his forefathers, had owned property in that county for several generations. David Reid was educated first at the parish school of Orwell, Milnathort, and subsequently at the High School of Glasgow, where he gave promise of future success in the profession for which he was being prepared. In 1856 he went to Canada as a pupil of his relative, Mr. George Lowe Reid, then the Engineer-in-Chief of the Great Western of Canada Railway, under whom he spent five years on the works of construction of that line and of its branches. Early in 1861, having acquired much practical knowledge of railway construction, he was engaged by the firm of Lee, Watson and Aiton to join their engineering staff on the works of a section of the Great Indian

Peninsula Railway, for which they were the contractors. When that work was finished he received an appointment on the engineering staff of Mr. Joseph Bray, contractor for a section of the same line in the Nizam's State.

In 1869 Mr. Reid entered into partnership with Messrs. Charnock and Mitchell, under the style of Charnock, Reid and Mitchell, for the reconstruction of the bridges on the Great Indian Peninsula Railway between Bhusawal and Nagpur, and for the maintenance of the permanent-way. In 1871 he, with Mr. F. D. Mitchell, tendered for, and was successful in obtaining, the contract for the construction of the Ceylon Government Railway, between Peredenia and Nawalapitya. Before the works were finished, his partnership with Mr. Mitchell was severed, and the extension was completed by Mr. Reid to the entire satisfaction of Mr. E. G. Strong, the Chief Resident Engineer, and of Sir Charles Hutton Gregory, the Consulting Engineer to the Government of Ceylon. On the completion of this work, he undertook the construction of roads in the coffee districts of the island, and the maintenance by contract of many miles of trunk roads. In 1877 he took in hand the contract for the construction of the branch railway between Kandy and Matale, under Mr. J. R. Mosse, Chief Resident Engineer. This was executed with great skill and despatch, for which he was highly complimented by the Lieutenant-Governor of the island.

His next public work was the construction, in conjunction with Mr. John Mackay, of Hereford, of the Jamaica Government Railway Extension, from Old Harbour to Porus, and from Spanish Town to Ewarton, under the direction of Mr. Valentine G. Bell, the Chief Resident Engineer, and of Messrs. Hawkshaw and Hayter, the Consulting Engineers. This line was remarkable for the successful construction of the whole of its bridges and viaducts in Portland cement concrete, there being no durable building stone in that part of the island. The railway was opened for public traffic in the year 1885.

In the meanwhile, Mr. Reid had devoted a considerable portion of his time and attention to the cultivation of tea in Ceylon. On the failure of the coffee plant in 1875–78, he had bought some abandoned coffee estates and a considerable tract of jungle land. He exhibited his usual energy and spirit of enterprise in this new industry, and was the first tea planter on a large scale who introduced the produce of his estates to the London market, where Ceylon teas in a few years acquired that high reputation which has steadily increased to the present day. His success in this enterprise induced him in 1886 to found the "Ceylon Tea Plantations Company," now one of the most prosperous undertakings in the island.

On returning to England in 1881, Mr. Reid settled in his native county on the estate of Thomanean, within a few miles of his birthplace, and there spent the remaining eleven years of his life, devoting himself to various public duties. He was elected a member of the Orwell School Board, Vice-Chairman of the County Council, and Captain of the "G" Company of Argyle and Sutherland Volunteers. His public spirit and force of character, combined with sound judgment, soon gained for him a leading position in the counties of Clackmannan and Kinross. Unfortunately, the strain of these numerous self-imposed labours proved too much for a constitution already weakened by a previous severe illness, and he was suddenly cut off in the midst of a life of unusual activity and usefulness, dying, after a brief illness, of peritonitis, at Thomanean, on the 13th of April, 1892.

Mr. Reid was a man of unwonted energy, ability, and steadfastness of purpose, and was held in great esteem by all who came in contact with him. Generous and large-hearted, he was ever ready to lend a helping hand to those deserving it. He married, while in Ceylon, Maria, a daughter of the late Sir William Bacon Johnston, Bart., and leaves a family of two sons and four daughters. He was elected an Associate of the Institution on the 7th of May, 1872.

⁂ The following death has been reported since the issue of Vol. cix.:—

Member.

BAILEY, JOHN, *born* 31 May, 1839; *died* 5 August, 1892 (*Peritonitis*).

It is particularly requested that members of all classes will furnish any information within their power as to the careers and characteristics of deceased members.—SEC. INST. C.E., 19 *August*, 1892.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Tripods for Levelling Instruments. By Dr. W. JORDAN.

(Zeitschrift für Vermessungswesen, 1892, p. 262.)

The construction of stands for levelling instruments requires special attention, inasmuch as in levelling the instrument has to be set up more frequently than is the case in surveying, fifty to one hundred settings-up being not unusual in one day. Any small saving of time is therefore of great importance. For levelling along high roads and in towns, the Author has found it useful, with a view to economising time, to insert a not too sensitive circular spirit-level in the top of the tripod. By moving the legs of the tripod, it is easy to bring the bubble to the centre of its circle, a process that may safely be entrusted to assistants. For levelling the instrument itself, merely a few turns of the screws will be required, since by the preliminary adjustment of the tripod legs everything has already been brought nearly to a horizontal position. In this way great rapidity can be attained. This method is, however, unsuitable for railway levelling, as a firm place must be found for each leg. In such case, a tripod with adjustable slotted legs, and a circular level has been found useful. Several other improvements in tripods for levelling instruments are described by the Author. A modification illustrated is that devised by Lallemand, in which there is a ball joint in the tripod head. A third modification is to support the level on a plate supported above the tripod head by three coarse adjusting screws. With an instrument of this kind the Author was able to level a railway at the rate of 1·5 kilometer (1 mile) per hour with a mean error of 2 millimetres per kilometer (0·13 inch per mile). It is advisable to employ two of these tripods, one being used to support the instrument, while the other is in front being levelled by an assistant. In this way the speed of levelling is greatly increased.

B. H. B.

The Cable Railway up Mount S. Salvatore, near Lugano.

By E. Strub.

(Schweizerische Bauzeitung, 1892, p. 35. 5 Figs.)

The Author states that Dr. Battaglini, of Lugano, obtained, in December, 1885, the concession of a rack railway from Lugano to the summit of S. Salvatore, and desired, two years later, that the concession should be given to him for a cable railway from Paradiso to S. Salvatore, and for a tramway from Lugano to Paradiso, with the option of using whichever of the methods he thought best. He also stated that the work would have been proceeded with if Messrs. Bucher and Durrer, of Kägiswyl, had not proposed to use a cable railway instead of a rack railway with locomotives. Dr. Battaglini finally gave up his earlier project, and obtained a concession for a tramway from Lugano to Paradiso, and a cable railway from the latter point to the summit of S. Salvatore. This concession he afterwards sold for £1,600 to Messrs. Bucher and Durrer, who commenced work in July, 1888, and finished it at the end of March, 1890. The cable railway begins near Paradiso, on the shore of the lake, about 655 feet from the landing stage; it then follows the St. Gothard railway in a straight line, and crosses the Calprinothal by the Ueberbrückungen to the middle station. The upper part begins with a curve of 980 feet radius, and 492 feet long, and then has a return curve of 980 feet radius, 328 feet long, and continues afterwards straight to the summit station. The total height reached is 1,973 feet, and the total length of both parts of the line is 5,356 feet measured on the grade, and 4,942 feet on the horizontal. The station of Paradiso is 920 feet, the middle station 1,620 feet, the S. Salvatore station 2,895 feet, and the peak of the mountain 2,981 feet above sea-level.

The grade of the line is at first 17 per cent., and reaches 38 per cent. at Pazallo, the middle station, while in the upper section it is finally 60 per cent. The lower part of the line is through a mass of loose material; the upper is either cut in the dolomite rock, or is carried upon walls specially built. The track is single, metre gauge, and only one car runs upon each part. A fixed motor at the middle of the line drives a cable-drum, and a car on each section, the cable passing over a drum at the highest point. In this way the two cars stand side by side at the middle station, so that passengers may change. The position of the motor in the middle was considered preferable, because it allowed cheaper cuttings, thinner cable, and obviated switching and unloading during construction, while allowing better housing for the attendants. Changing of passengers at the middle station is found to be easy. If traffic should greatly increase, automatic points can be placed in the middle of each half, and the number of cars can be increased. The permanent-way rests upon massive masonry, built upon horizontal ledges cut in the mountain; a string course at the top is set in cement. The lower part of the masonry is 23·4 inches high. The sleepers are of unequal-sided angle-bar, and stretch across the top of the wall, which is 4·9 feet wide. Their short sides are set in cement mortar. The sides of the masonry of the upper section are coated with cement, to prevent weathering. The S. Salvatore dolomite is not good for such work, so stone, water, and sand had to be brought from a distance; a portable engine was placed at the mid-station, and the materials raised by a wire-rope. The space between the car and the sides of the cuttings is 16·5 inches, and between it and the signal posts was 25·25 inches. Niches are provided at distances of 98 feet apart, for the security of the workmen, and steps are cut to facilitate ascent. The chief points worthy of note are the bridges over the Gothard railway cutting and over the Calprinothal, and five stone crossings over the Calprino and other roads. Both of the bridges are of similar construction and strength. The first has two spans, 50 feet wide, and the other six spans, of 51·5 feet and 58 feet wide. The Author gives details as to the bridges, from which it appears that their weight, including permanent-way, is 900 lbs. per yard. The sleepers weigh 30 lbs. per yard, and are placed 3·35 feet apart.

In order to secure the rails against being torn out by the sudden use of the brake every second sleeper is anchored into concrete by bolts 19·5 inches long. From tests made upon the unanchored rails to prove their resistance to lifting, it was found that when the rack was loaded to 3 tons at its working point, and a vibratory motion given to it, there was neither loosening of the sleepers nor movement in the masonry.

The rails, which are 26·6 feet long, 3·5 inches high, weighing 35·5 lbs. per yard, are fixed down by cramps and screws. The side strain upon the anchor bolts is 110 lbs., caused by the side pressure produced by the eccentric position of the cable. The Abt rack is almost exactly similar to that used at the Burgenstock railway. The cars have two axles and four half-open compartments, each containing eight seats of the same class. At each end of the car is a platform for the driver. The floor of the lower car is horizontal, on a grade of 28 per cent., and the upper car on one of 50 per cent. Each car weighs 4½ tons, and both are alike with the exception of the doors, which are on opposite sides, to facilitate changing.

Particulars are then given of the construction of the cars.

Both hand- and automatic brakes are fitted, and the derailing of the cars is prevented by hooks, which pass under the head of the rails.

The cable has a factor of safety of 9·5, with a load of 5·3 tons; it has a diameter of 1·24 inch, weighs 6·9 lbs. per yard, and is composed of steel wire. From the lower car it runs to the power station on to the driving drum, 13 feet in diameter, then to an idle pulley 9·8 feet in diameter, back to the driving drum, and off the idle pulley up to the top of the line, and round a drum 11·4 feet in diameter.

The cable is guided by suitable rollers, with renewable wood facings.

The power for the railway is obtained from a spring near Arogna, whence the water is brought a distance of 3·1 miles by a pipe, into a small reservoir above Maroggia. The pressure-pipe is 19·5 inches wide, and the fall to the power-house is 830 feet, and will develop 700 HP. As yet only part is used by means of two Girard turbines with horizontal shafts; the larger of these, giving 250 HP., drives an alternator with its exciter, and the other, of 125 HP., drives the dynamo used for the transmission of power. The larger plant is used for lighting the town of Lugano. Suitable governors are so arranged as to control the water-supply and obtain a constant speed of 750 revolutions per minute at the machines. The turbines are connected to the dynamos by flexible leather couplings.

The dynamo for the railway gives out 60 HP. at 700 revolutions per minute, developing 1,800 volts and 22 amperes. From the power-house at Maroggia a copper wire 0·195 inch in diameter is carried a distance of 7,826 yards to the sub-station. Upon the same posts is carried the lighting wire, and also telephone and lightning protector. Oil insulators, of Messrs. Johnson and Phillips' type, are used. 150 volts are lost in transmission, and the output of the motors is 43 HP., giving a combined efficiency of 71·5 per cent. A portable engine of 50 HP. is kept in reserve, in case of repairs being required to the turbines. The main shaft is driven from the motor or engine by belting, and this actuates the rope-drum by spur- and bevel-gearing. The direction of motion is controlled by a movable friction coupling. The Author then gives details as to the various instruments in use, and as to the brake-power. The speed at which the cars travel is 3 feet per second. The various signals are given by telephone, and a special wire is carried between the rails, so that the car-conductor can make connection and give bell signals also.

The Company has a capital of £16,000 in shares, and £8,000 in mortgage debentures.

The number of persons carried the first year was 33,886.

The cost of the whole work was—

	£.
Designs, &c., purchase of concession	1,600
Purchase of land	1,000
Construction of line	11,600
Permanent-way	4,000
Working material and furniture	800
Management and interest on buildings	1,600
Buildings and plant	2,600
Unforeseen expenses	800
	24,000

The whole journey, including the change at the middle station, takes thirty minutes, and the price of the ticket is 2*s.* 6*d.* up, 1*s.* 8*d.* down, and return ticket 3*s.* 4*d.*

Work was only stopped for five days last winter owing to snow.

E. R. D.

The Construction of the Milseburg Tunnel.

By L. OBERSCHULTE.

(Zeitschrift für Bauwesen, 1892, p. 47.)

This single-line tunnel, constructed in 1887-89, is situated upon the Fulda Tann Railway, a branch from the main Fulda-Bebra line, which latter forms part of the route between Frankfort-on-the-Main and Hanover. The branch commences at about 3 miles north of Fulda, and a spur of the Röhn chain, forming the watershed between the valleys of the Fulda and Ulster, is pierced by this tunnel. Its length is 1,258 yards, and the gradient throughout is 1 in 50, the difference in level between the eastern and western ends being 75·46 feet. The western entrance being the lower, the headings and works were driven entirely from that end, on account of drainage and of transport of the excavation. With a view to diminishing the effects of frost, together with the strength of the air-current which might be expected in a tunnel of which the lower entrance is about 1,683 feet above sea-level, and in which the difference in level of the two portals is so considerable, the course of the tunnel at the western end is on a curve of 22⅓ chains radius, extending inwards for about 273 yards from the entrance, the remainder of the length being straight. The strata passed through were of the trias order, and much difficulty was experienced at many points, owing to the pressures induced by the gradual movement of the sandstone beds, of soft character, under the influence of the escaping water, necessitating very heavy timbering during the driving of the headings, and the final lining of the tunnel throughout with masonry, including an invert, altogether requiring about 26,000 cubic yards of stone.

To obtain the latter, a quarry was opened in the hillside, near the western entrance, about 230 feet above the level of the line, and the stone transported by a specially-constructed balance incline railway, worked by wire-rope and drum in the ordinary way.

The main dimensions of the tunnel are a width of 16 feet 8 inches, and a height from rail-level to soffit of 18 feet 1 inch.

A large area at the western entrance was laid out as a works yard, with sidings, stores, workshops, and offices, and here also were erected the boilers and machinery for the rock-drill air-compressors, the electric lighting, sand-washers, mortar-mills, &c. There being no good road leading near the site of the works for the conveyance of material, a temporary line of 3 feet gauge was laid for a length of 1½ mile, of which the greater part lay along the course of the future railway, and this gauge was used for the temporary road in the tunnel heading. Two small locomotives, with hinged lowering funnels, were used for transporting the excavation from the tunnel. Their weight was 6⅔ tons empty, and the working pressure was 220 lbs. per square inch. The height from rail to the funnel hinge, with the upper portion lowered, was 6 feet 4½ inches, to enable the engine to pass through the heading, which was only 7 feet 2½ inches high. Arrangements for condensing the steam in a tank under the engine, and for preventing the direct escape of smoke and gases by throttles in the smoke-box, are described, a holder containing lime-water being intended for the absorption of the carbonic oxide; but the method adopted in practice was to start with a full pressure of steam and a clear fire, which was not again interfered with while in the tunnel, the greater part of the gases being collected in the smoke-box. A load of four stone-laden wagons, or 13 cubic yards of stone could be conveyed 0·62 mile in the tunnel, the steam-pressure during the journey falling from 220 lbs. to about 80 lbs.

The Belgian method of procedure was adopted for the excavation of the tunnel, and a diagram is given showing the order in which the segments of the cross-section were removed; also a series of diagrams showing the method of timbering the main heading (Sohlenstollen) and the arch gallery (Firstollen), and longitudinal sections and tables showing the progress throughout the term of the works. Boring by hand was at first used, but was soon abandoned for compressed-air machine boring, the advance made with the latter being from 82 to 120 yards per month of twenty-five working days. The machine used was the Jäger, weighing 187 lbs., which could be worked under a pressure as high as 88 lbs. per square inch, although that generally used was from 50 to 60 lbs. The blows delivered are not heavy, but very rapid in succession, viz., from five hundred to six hundred per minute. Six of these machines were provided, of which, however, only two were in use at one time.

A description is given of the electric lighting arrangements of the tunnel works, the workshops and offices, and of the yard and the quarry. Glow-lamps were used for lighting the offices, workshops, and the actual tunnel works, and arc-lamps in the yard and quarry, the latter also being used in the tunnel as it neared completion.

The advantages of electric lighting in place of rape oil, for tunnel works, are set forth, and include the non-contamination of the air, and better work and easier supervision ensured by the superior illumination.

The number of men in the working gang, and their duties, are enumerated; their wage and the cost of blasting material (gelatine) are given, together with the quantities and cost of timber, &c.

The total cost of the tunnel, 1,258 yards in length, was about

£41,500, of which £1,500 was for plant, leaving £40,000 for actual construction, or £31 15*s.* per lineal yard (695 marks per lineal metre).

D. G.

The New Railway-Station Arrangements at Frankfort-on-Main. By H. Wegele.

(Zeitschrift für Bauwesen, 1891, p. 83.)

The Author, in a series of articles extending throughout the year, describes very fully the past and present railway station arrangements of Frankfort and the gradual growth of the traffic and enlargements of the old stations. He then reviews the various projects dating from 1865 onwards to that finally decided upon, the design of Mr. Hottenrott in 1879, for the institution of a joint passenger-station and the laying out of goods and marshalling-yards in place of the then existing three distinct termini, in the western suburb of Frankfort.

The new passenger-station and the goods yards and shunting and marshalling-yards, are situated at the western end of Frankfort, and were opened for traffic in August, 1888. They take the place of the old group of "the western" stations, comprising that of the Taunus Railway of 1839, the Main-Neckar Railway of 1846, and the Main-Weser of 1850, which have been swept away and their sites utilized by the municipal authorities for streets forming approaches to the new stations, and for general building purposes. Among the numerous plans accompanying the Paper is one showing the old western railway stations and the vicinity, also a general plan showing the position of the new passenger station and of the yards, and, by dotted lines, the sites of the old works.

The adopted design differed from the various earlier suggestions, in that the State railways and the Hessian Ludwigs Railway each have a distinct goods and marshalling, &c., yard, the longitudinal axes of which are directed towards the centre of the town, and thereby give freedom for the growth of the city in that direction, instead of, as in the earlier propositions, having the station and embankments stretching from the suburb of Bockenheim in the north-west, southwards to the river, thereby erecting a permanent barrier which would prevent any further extension of the town on that side.

As constructed, the longitudinal axis of the principal passenger-station is parallel to the river Main and at about a third of a mile from the latter, having a north-east to south-west direction, with the main front, containing the entrance-hall, &c., at the north-eastern end, and lying a little to the south-west of the sites of the old western stations which it replaces.

On large scale plans are shown the arrangements of lines and sidings in the passenger-station, in the goods and marshalling, &c.,

yards of the Hessian Ludwigs Railway, and in the goods and marshalling, &c., yards of the State railways.

In the passenger-station the railways accommodated are the lines of the Hessian Ludwigs Railway coming from a south-westerly direction, including Mainz and Limburg and the lines of the State railway. The former company has apportioned to its use about one-third of the accommodation, and has subscribed to the cost of construction in about that proportion. The State railways include the Taunus Railway coming from Wiesbaden, the main Neckar Railway from Darmstadt in the south, and the Main-Weser Railway from Cassel in the north-east. The course of the latter, between the stations of Bockenheim and Louisa, is nearly at right angles to the axis of the station, and crossing the river Main by the Staatsbahn bridge, is carried at a high level across the Hessian Ludwigs Railway, and connected with the station by a spur line in each direction of 15 chains radius on a falling gradient.

The goods yard of the Hessian Ludwigs Railway and the marshalling and shunting yard of that railway, lie parallel with and close to the northern side of the passenger-station and the main lines approaching it, whereas the goods yard and the marshalling, &c., yard of the State railways, which are much more extensive, lie nearly ½ mile further to the north, having an east and west direction. The connection between the high-level main line of the State railways and the goods and marshalling, &c., yards is, as in the case of the passenger-station, by curves of 15 chains in each direction on a falling gradient. As regards the State railways, detailed descriptions are given, with references to the plans accompanying the Paper, which show the sidings as at present laid in and as proposed to be extended hereafter. The methods of shunting and marshalling the wagons by gravity is also described, and diagrams and Tables are given of the points and signal locking apparatus.

In the goods yard the wagons are handled with the aid of hydraulic capstans.

The main goods-shed, in cross-section, is formed by a wrought-iron trussed centre span of 52 feet 6 inches, and a 26 feet 9 inches span on each side, carried on cast-iron columns; the height from the deck to the ridge is 19 feet, and the height from the rails to the goods-deck is 3 feet 8 inches. There are two radial locomotive standing sheds provided, but of which segments only are at present erected. These are now capable of taking fourteen engines and ten engines respectively, and can be each enlarged hereafter to take forty-four engines.

The repairing-shops for locomotives and for passenger carriages are described, as also those for goods wagons.

At the western abutment of the Staatsbahn bridge, over the Main, there is a pair of hydraulic lifts for transferring wagons to or from the high-level line and the sidings upon the river quay. A load up to eighteen tons and with a maximum wheel-base of

18 feet, can be raised the full lift of 18 feet in thirty seconds, the water-pressure being 1,100 lbs. per square inch. The time occupied in completing the operation of raising a wagon and the return ready for the reception of another is six minutes, so that with both lifts in use twenty wagons may be raised per hour.

The passenger-station, together with the booking-hall, waiting-rooms, and offices, are very fully described and illustrated by general and detail drawings and by photo-lithograph views of the exterior and interior.

At the eastern end of the station-hall is the building forming the main front and comprising the booking-hall, waiting-rooms and restaurants, flanked by the offices of the State railway on the southern side, and by those of the Hessian Ludwigs Railway on the other; there being a large open space, laid out partly in ornamental garden, forming the approach from the town and into which four or five thoroughfares converge. The width of the façade of this building is about 690 feet, and its depth, from the face to the back of the booking-hall, about 197 feet, and elsewhere about 105 feet.

The lofty booking-hall is about 104 feet 6 inches broad, and 183 feet 9 inches long, and contains, in addition to the ticket offices, the luggage-receiving, postal and telegraph offices; to the left side of this, access is gained by a corridor to a range comprising a first- and second-class waiting-room, a third- and fourth-class waiting-room, and a restaurant. To the right of the booking-hall this arrangement is repeated. The waiting-rooms are each about 74 feet 2 inches by 46 feet 6 inches, and of considerable height.

The station-hall, which is formed transversely by three arched spans of 183 feet 9 inches, each with a clear height to soffit of 93 feet 10 inches, is 611 feet 6 inches long, and 551 feet 3 inches broad. There are eighteen separate tracks running into the station, and nineteen platforms, each 984 feet long, and varying from 13 feet 9 inches to 31 feet 6 inches in breadth; these terminate at the eastern end in a transverse platform of about 58 feet 6 inches in width, next the booking-hall. The height of the platforms above the surface of the rails is 8¼ inches.

At the western end of the hall the platforms are connected transversely by a tunnel divided into three sections—for passengers, luggage, and postal service respectively, the former being gained by stairways at each platform. The breadth of the passenger subway is 13 feet 11 inches, of the luggage subway 9 feet 10 inches, and of that for the postal service 14 feet 9 inches; the height to the springing is 8 feet 3 inches in each case, and, as the floor of these subways is 2 feet 3 inches below the level of the highest land-water, the lower portion of the walls is laid in cement.

The station-hall, as above-mentioned, is transversely in three spans, formed by arched principals springing from stone bases a foot or two above platform-level. These principals are, in most instances, 30 feet 6 inches apart from centre to centre.

The arch is formed by a compound curve varying from 78 feet to 110 feet 5 inches internal radius; the depth of the arch varying from 7 feet at the haunches to 1 foot 3¾ inches at the crown. There is a transverse ridge and valley skylight in each span, 103 feet 4 inches in width, running nearly the whole length of the hall, and occupying about $\frac{4}{7}$ of the entire area of the roof.

The remainder of the roof is covered with corrugated galvanized iron, weighing 1·9 lb. per square foot. Details of the skylight, weights of glass, &c., are given.

The arched principals are hinged at their springing and at the crown. They are twenty in number and of similar form throughout, with the exception of those near each end, which, in the one case, at the western end, have to carry the additional weight of the screen, and at the eastern end, where they are 60 feet apart, instead of 30 feet 6 inches, to give sufficient width for the exit arches; also the springing of the easternmost principal is at a much higher level than the others, being 36 feet above platform-level.

In erecting the roof, three travelling centering stages, each 42 feet in width, were used; the rail tracks, upon which each ran, being four in number and about 2 feet 9 inches gauge.

The details of the ironwork are given, together with the calculations of the strains and the assumed weights; also the tests specified for the wrought-iron plates, angles, &c.

The assumed maximum wind-pressure was 30¾ lbs. per square foot, and the allowance for snow was 16½ lbs. per square foot, where the angle of roof was less than 30°.

The total cost of the passenger station, goods yard, and marshalling and shunting yards and works in connection therewith, amounted to £1,754,100.

D. G.

Canal from Havre to Tancarville. By MAURICE WIDMER.

(Annales des Ponts et Chaussées, May 1892, p. 633.)

This Paper contains an exhaustive account (172 pages) of the above canal, which has been constructed to enable barges navigating the Upper Seine to reach the port of Havre, the estuary of the river being too wide and exposed for such vessels to navigate it. Strong opposition was made to the canal, on the grounds (1) that barges would not be able to descend the Seine so far as the entrance to the canal at Tancarville; (2) that the engineering difficulties were insurmountable; (3) that the canal would not be used, even if successfully completed. All these predictions have been falsified by the result. During the five years that the canal has been in operation it has been entirely successful, and one of its effects has been to cause a reduction in railway rates between Paris and Havre of two francs per ton.

The total length is 15½ miles, and the upper entrance is 60 miles below Rouen at Tancarville. The water-level of the canal is fixed at 3 feet 3 inches below the mean level of the adjoining lands, which are on the level of high-water of equinoctial spring-tides. It is thus 4 feet 3 inches above high-water of extreme neap tides at le Havre. At Tancarville the canal is 6 feet 6 inches below high-water of spring-tides, and 14 feet 6 inches above low-water of spring-tides.

The depth of water in the canal is, in general, 11 feet 6 inches, or one foot more than in the Seine above Rouen. The locks are 52 feet 6 inches in width at the gates, the chambers being 590 feet long by 98 feet wide. There is one lock at each end, each furnished with two pairs of gates closing in opposite directions.

The works described in the Paper comprise, besides those above mentioned, several swing bridges, the hydraulic machinery for the gates, sluice paddles, and capstans, the temporary works and plant required for construction, and the electric light installation for night working of the lock at Tancarville. An appendix contains the calculations on which were based the design of the swing bridges, gates, hydraulic machinery, and pumps for supplying the lock at Tancarville. It was found in practice that it was impossible, when admitting the Seine-water to the lock, to keep it free from deposits of silt, and for that reason pumps are being established to feed the lock with clean water from the canal.

It would be impossible, within the limits of an abstract, to give any description of the works which would convey the character of a Paper so elaborate, but the following points may be selected as possessing particular interest.

The lock-gates at Tancarville are made in one leaf (those at le Havre being mitred in the usual way), and the Author adduces very strong arguments to show that it is a preferable plan. He also describes certain accidents which would have been much more serious with mitred gates than they proved to be with the single-leaf system, and says that the experience of three years with them goes to confirm the correctness of the choice. These gates are rectangular in elevation, and ship-shaped in cross-section, with floatation chambers, and closing on a plane surface at the heel, in the fashion usual in France, instead of having a watertight joint in the hollow quoin.

The gates at the Havre lock are operated from the engines of the hydraulic capstans, the connection being made by lines of shafting with spur gearing, which can be thrown in or out, as required.

All the gates are constructed on the principle of distributing the water-pressure by means of vertical girders between the sill on the one hand, and a main horizontal girder at the top of the gate on the other. A subsidiary system of horizontal and vertical girders divides the surface into sections small enough to be covered by unsupported plating. The materials for the gates were galvanized, the rivet-heads painted with zinc-white, and the timbers for keel and mitre posts, &c., were oak, copper-sheathed. The swing-bridges are designed to turn on a water-centre, being clear of the pivot when closed. The water-pressure is, however, insufficient to lift the bridge. The plunger of the central hydraulic cylinder remains in contact with the bottom of the cylinder, in order to avoid the risk of accident to the bridge from any sudden failure of the hydraulic pressure.[1]

Full particulars of cost are given, the total amounting to £940,000. The article is very fully illustrated by thirteen sheets of engravings.

C. F. F.

New Outfall of the Vistula formed by Flood in 1840, *and its Subsequent Development.* By — LIERAU.

(Zeitschrift für Bauwesen, 1892, p. 29.)

The Vistula, known from where the Nogat leaves it at Montauerspitze as the divided Vistula (Getheilte Weichsel), near Rothebude, about 15 miles from Danzig, divides again into the Elbing Vistula, which runs eastwards and empties into the Frische Haff, and the Danzig Vistula, which flows into the Baltic. The only mouth of the latter was, previous to 1840, at Neufahrwasser, about 3 miles directly north of the town of Danzig, and the Nogat at that time took about two-thirds of the volume of the Upper Vistula, the remaining third being divided about equally between the Elbing and Danzig Vistulas, unless disturbed in winter by an excess of ice flow in one or other of these branches.

At Neufahrwasser, the mouth of the Danzig branch, outward-bound vessels left the river by a cut running in a westerly direction, and leaving the river about $\frac{1}{3}$ mile above the natural mouth, and this also is the existing condition of things as regards navigation.

The general direction of the Danzig Vistula above the town is, for about 9 miles, parallel to the coast, the narrowest neck in the strip of intervening land, comprising the marshes or flats and a chain of sand-hills or dunes, being at the village of Neufahr, about 5½ miles (9 kilometres) east of the then existing outfall of the river at Neufahrwasser. It was at this neck, during the night of January 31st and the morning of February 1st, 1840, the river being filled with ice, that a breach was made in the sand-hills, and a new outfall for the river constituted.

For some days previously ice had been accumulating in the

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[1] Minutes of Proceedings, Inst. C.E., vol. cix. p. 446.

Nogat and the Elbing Vistula, at their off-branching, until at last, these becoming blocked, the main flow of water and ice was diverted into the Danzig branch, in which it rose until the right embankment, near the village of Bohnsack, was breached and the flats flooded. The lake thus formed was for a short time hemmed in a little below Neufahr by some higher lying ground and an embankment, until at last, near that point, it burst through the sand-dunes and formed a permanent outfall. The Paper is illustrated by a general plan of the coast and river near Danzig, and by a series of sixteen charts, showing the newly-formed river mouth at Neufahr, and its variations as regards shoals, training works, &c., that have been carried out between 1840 and 1890.

This accidental creation of a second outfall of the river appears to have produced a condition which had been recommended as actually desirable in the reports of various public officials early in this century, as hereby a long stretch of former stream is canalized by the construction of lock gates at the point where the new river outfall branches off, and the old mouth is no longer the passage through which the ice from the upper waters flows on its way out to sea, and in addition the new conditions are favourable for the purposes of the defence of Danzig in case of siege.

The cost of the lock-gates and works, constructed in timber, and opened for navigation in July 1841, was £16,656, the breadth of the lock-entrance being 41 feet 2 inches, and the length of the lock-chamber 206 feet.

By this alteration of the river, the course of the Danzig Vistula from the Danzig Haupt, or point at which the Elbing Vistula branches off, to the outfall, is shortened by 9⅓ miles, and the former fall, in that length, of 2 feet 6 inches in the summer season, or 8 feet 2 inches in the flood season, is gained, with the result that instead of, as formerly, the volume being divided between the Elbing Vistula and the Danzig Vistula, the greater portion now comes down the Danzig branch with an increased velocity and consequent wearing away of the banks and deposit of a delta.

The charts above referred to show the condition of matters at various dates between 1840 and 1890, and the various works commenced and prolonged from time to time, with their effects upon the sand-banks as regards the alteration in the position, or the removal of the latter; they also show the variation in the lines of soundings, and diagram sections are given of the parallel works, &c.

The amount expended upon regulation works, from 1873 to the year 1890, amounted to £66,828.

D. G.

The Deep Boring at Teplitz.

(Allgemeine österreichische Chemiker- und Techniker-Zeitung, 1892, p. 1108.)

The supply of water from the thermal springs at Teplitz having been endangered by mining operations in the neighbourhood, it was decided to sink a bore-hole 500 metres (1,640 feet) deep, in order to obtain a supply of water from a level lower than any of the mine workings. The first attempt was a failure, owing to the extremely hard rock which was encountered and the numerous fissures traversing it.

A second bore-hole was then commenced, and is described in this report of the Committee. The system adopted was the American rope-drilling one, and the diameter of the bore in the first instance was 10½ inches. The site was 692 feet above sea-level. The work was commenced on the 6th of May, 1890, and abandoned on the 22nd of April, 1892. The first formation pierced was limestone 21 feet thick, followed by a layer of hornstone of 3·28 feet. Then the porphyry was struck, and the rest of the work was carried out in this rock. At a depth of 32 feet, the diameter of the tube with which the bore-hole was lined was reduced to 8 inches, and at 52 feet the first thermal water was struck with a temperature of 109° Fahrenheit. The maximum temperature of water was reached at 182 feet, where it was 118·5° Fahrenheit. The first serious accident happened at 429 feet, when the sides of the bore-hole fell in, wedging in the tools and causing a delay of four days. At 489 feet, a similar accident occurred, through which twelve days were lost. Until a depth of 921 feet was reached, similar interruptions were frequent. The bore-hole was then lined with pipes 6 inches in diameter; but this produced no alteration either in the level or the temperature of the water.

Work proceeded without difficulty until a depth of 1,223 feet was reached, when falls of rock and consequent wedging of the boring tools became so frequent that it was decided to fill the bore-hole with concrete from the lowest point reached up to the lower end of the iron tube. This work occupied five days, after which eight days were allowed for the setting of the concrete. Work was then recommenced, and the concrete successfully perforated. Boring was continued in the porphyry to a depth of 1,259 feet, when a second filling of concrete became necessary. This had the desired effect, and the solid porphyry was further pierced to a depth of 1,268 feet.

The falls of rock now prevented further progress, and it was decided to draw the 6-inch lining and increase the diameter of the bore-hole to 8 inches. The lining was successfully extracted; but in increasing the size of the hole great difficulty was encountered. The porphyry was intersected by numerous fissures at an acute angle to the axis of the bore-hole, and these caused the boring tools to deviate from the perpendicular. By driving in wedges of oak and drilling through these the bore-hole was kept straight, and continued until a depth of 1,075 feet was again reached. Here the boring tool was lost, being so tightly wedged in that all efforts to extract it were unsuccessful. It was then decided to abandon the bore-hole and to commence a third one, perhaps of greater diameter. The water has now risen to a height of 38 feet below the surface, and its temperature is 111·5° Fahrenheit.

The cost of the first bore-hole was £1,658, and of the second £6,668.

Although the bore-holes did not attain the desired depth, yet they demonstrated the presence of very large quantities of thermal water throughout the porphyry pierced.

W. F. R.

The Des Moines, Iowa, Stand-pipe.

(Engineering News, New York, 1892, p. 346.)

This stand-pipe was erected without scaffolding, in the months of September and of January, and the method employed, although not entirely novel, having been adopted for a stand-pipe in Atlantic City, N.J., in 1883, is worthy of notice.

The following is a general description of the structure. The height of the stand-pipe is 100 feet, and its diameter 30 feet. It is formed of steel plates in courses of 5 feet in depth, the horizontal joints are single-riveted throughout, the vertical joints double-riveted, and, in the two lowest courses, treble-riveted. The thickness of the plates varies from $\frac{7}{8}$-inch at the base to $\frac{1}{4}$-inch at the top.

The top of the pipe, or tower, is covered with a floor formed of 12-inch rolled joists, supporting 2-inch planking, and a top flooring of 1 inch hard pine. Access is gained to this platform or "Observatory," which is protected by a wrought-iron balustrading, by a similar balustraded stairway of easy grade winding around the tower.

In the centre of the platform is an opening or well-hole 4 feet square, protected by a trunk carried up to 7 feet 9 inches above the floor, and covered at the top with close mesh galvanized wire-netting. The standards supporting the roof are of tee-bar, giving a height from the platform to the eaves of 10 feet 3 inches. The roof itself is conical, 18 feet 3 inches high, and formed of a framing of tee- and angle-bars sheeted with bulged burnished copper plates. The foundations are of concrete; the natural earth, which is a firm tough clay, being left high in the centre of the foundation area, so that the concrete forms an inverted cup retaining the core of earth, and preventing it from spreading.

By adopting this method, it is estimated that 80 cubic yards of concrete was saved.

Regarding the method of erecting the stand-pipe: a "floating platform," formed of 12-inch balks, overlaid with two layers of 2-inch planking, and of 29 feet 9 inches diameter, or 3 inches less than that of the interior of the pipe, was made and bolted together in such a manner as to be readily taken asunder. For anchoring the float rings and stanchions were let into the platform, through which and temporary lugs bolted to the pipe wall chains could be rove. Rising from the centre of the float was a derrick formed by a mast of 12 feet in height, and a boom 25 feet long. On the top of the mast was a plate carrying eight guys, of which six were always fastened to the edge of the stand-pipe to prevent the float tilting while hoisting and fixing a plate. The hoisting-rope passed from the mast-head over a bracket affixed to the edge of the stand-pipe to the hoisting engine below.

The forges, the holders-up and helpers were carried on this platform, and outside the stand-pipe were slung two cages for the riveters; the entire number employed being eight men and two boys, and the time occupied in riveting a 5-feet course of plates was fifteen hours.

The lowest course of pipes having been riveted up and connected with the base-plate *in situ*, the floating platform was put together, and water supplied from the city main, pumped in through a hose, the platform rising with the progress of the work, and in this manner the whole tower was riveted together. After completing the main process of erection it had been intended to rivet up the angle-bar brackets, for supporting the spiral stairway, from this same platform, by lowering the water, but it was found that a coating of ice lining the walls to a thickness of 18 inches on the north side and 2 inches on the south side, had been formed, so that a smaller raft had to be used.

D. G.

The Penetration of Impurities into Service-pipes Conveying Water under Pressure. By G. OESTEN, of Berlin.

(Gesundheits-Ingenieur, 1892, p. 345.)

The Author states that it is a commonly received opinion that pipes conveying water under pressure can, under no conceivable circumstances, permit of the entry into them of impurities from the soil. This impression is, however, erroneous, for cases are possible in which a hole in the pipe may, owing to the direction of the same, and that of the flow of water along the pipe, give rise to an action resembling that of an injector, and cause external impurities to be sucked into the water-supply. By reference to a diagram, it is shown that if the direction of the hole is opposed to the flow in the pipe, or at right angles to the same, the water, whatever the internal pressure may be, will always tend to rush out in the form of a jet. If, however, the direction of the aperture is obliquely inclined towards the current, when the flow in the pipe reaches a certain velocity, it will exert a sucking action, similar to that of the injector.

This has actually happened in connection with a house-supply in Berlin. The imperfection occurred in a stop-cock, the exterior of which became worn through, and by reference to diagrams it is shown that, in certain positions of the plug, an inclined slit was formed through which sand and grit were drawn into the main. These gave rise to a deposit which so much injured the taps and fittings as to cause an investigation, and ultimately led to the detection of the injury.

G. R. R.

On the Durability of India-Rubber Hot-Water Pipes.

By E. Belleroche.

(Revue Universelle des Mines, vol. xviii., 1892, p. 25.)

On the Grand Central Railway of Belgium the warming of the carriages by hot water circulating through pipes connected by india-rubber coupling tubes from carriage to carriage, was introduced in 1882, and from that date observations have been made in order to determine the average duration of the most destructible elements in the system, namely, the connecting pipes. On the Charleroi and Vireux section of the line, where the first experiments were made, the number of pipes in use increased from twenty-six in 1883 to eighty-nine in 1891, whose ages at the end of each year are given in the following Table:—

—	1883	1884	1885	1886	1887	1888	1889	1890	1891
1 year old .	26	56	8	5	10	9	48	5	10
2 years old .	..	26	56	7	5	10	8	48	5
3 " " .	..	..	26	56	7	5	10	8	48
4 " " .	..	..	..	26	52	7	5	8	8
5 " " .	..	..	..	..	20	42	6	4	7
6 " " .	..	..	..	..	..	13	29	4	3
7 " " .	..	..	..	..	..	..	11	14	0
8 " " .	..	..	..	..	..	..	..	10	8
9 " " .	..	..	..	..	..	..	..	..	0
	26	82	90	94	94	86	117	101	89

From which it appears that no loss was experienced on the original number of twenty-six for four years, after which they became worn out in increasing numbers, and were entirely gone at the end of the ninth year. The mean age of the tubes at work at the end of 1891 was 3·5 years. The total number of tubes worn out during the period under review was eighty-eight, whose ages were:—

Below 1 Year.	1 Year.	2 Years.	3 Years.	4 Years.	5 Years.	6 Years.	7 Years.	8 Years.
0	2	0	6	19	23	21	7	10
0	2	0	18	76	115	126	49	80

The products of these numbers contained in the last line when added together gives four hundred and sixty-six tube years, and this divided by eighty-eight gives 5·3 years as the average duration of the pipes—a period which the Author hopes will be increased by the adoption of a new system of connections which will materially diminish the wear and tear incidental to coupling and uncoupling the carriages.

H. B.

Public Shower-Bath at the Wilhelmithor, Brunswick.

By CURT RANDEL.

(Gesundheits-Ingenieur, March 15, 1892, p. 137.)

The conditions are laid down which must be observed in the case of a public bathing establishment of this character. Separate baths for each person must be provided at such a cheap rate as to be accessible even to the poorest classes. A bath of this kind must be a cleansing bath, and permit of the abundant use of soap, and lastly, the bath must be rapidly prepared and capable of being quickly used, as the time at the disposition of the bathers is generally very limited. The credit of devising these public shower-baths is due to Dr. Lassar, who, as far back as 1883, had one on view at the Berlin Health Exhibition, and his system has been since then adopted at Berlin, Magdeburg, Frankfort, and many other towns, with marked success. By reference to drawings the Author explains the arrangement of the new baths at Brunswick.

The site covered by a one-storey building occupies an area of 14 metres square (about 46 feet × 46 feet), half of which space represents the size of the cellars. Separate arrangements are made for men and for women bathers; fifteen shower- and two slipper-baths for the former, and six shower- and one slipper-bath for the latter. It is found by experience that there are comparatively fewer women than men who use the shower-baths, and, therefore, on the women's side some of the cells are given up to seated douche-baths (*Sitzdouchen*). The heating apparatus for the water —a vertical boiler with 16 square metres of heating surface—is placed in the cellar, and the water circulates from this to a reservoir in the roof, with a capacity of 704 gallons. A hot-air apparatus serves not only to warm the building, but also to heat a drying-stove for linen, &c., and there are tubs for washing and rinsing purposes for linen in the basement, as also the drying closet and a mangle. The cell for each bather is 8·2 feet × 4·9 feet; the hot-water douche flows through a 50-millimetre pipe, and the tap is of special construction, so as to limit the supply of hot water and to prevent waste. The supply of cold water is not limited. The various parts of the special taps for the spray are explained by reference to diagrams. The charge for each shower-bath, including use of soap and towel, is 1*d.*, and for a slipper-bath the charge is 2*d.* The total cost of 27,000 marks (£1,350), or 1,125 marks (£56·25) per bath-cell, compares favourably, as the Author shows, with the cost of similar establishments elsewhere.

G. R. R.

Report on the Results of the Rearing of Fish in the Effluent Water from the Berlin Sewage-Farm at Malchow.

By G. Oesten.

(Gesundheits-Ingenieur, May 15, 1892, p. 289.)

After a brief account of the origin and nature of the water employed for these experiments, and a statement that the sewage-water distributed over the land, before passing through the soil, acted as a deadly poison upon all kinds of fish, the Author points out that Professor Virchow had once hazarded the opinion that, because the effluent-water supported numerous mollusks, it probably would be found suitable for fish. In consultation with Dr. v. Behr, the Author had several times discussed this matter, and was urged by him to place some trout fry in Lake Malchow in the winter of 1887. Before doing so, however, he deemed it expedient to ascertain, by an experiment in the channels on the farm, whether fish would live in this effluent-water. In the spring of 1887, and again early in 1888, some small fry of trout and salmon-trout were placed in the ditches and remained there for several weeks. With the assistance of Mr. Spinola, two improvised ponds were prepared in 1889, with inlets and outlets under proper control, and these were stocked, the one with trout fry and the other with young char. In consequence of an accidental breakage of the dams, both of these ponds were emptied into Lake Malchow, but not before the young trout had shown that they were able to flourish in effluent-water and to withstand the summer heat and the winter ice in shallow ponds. In 1890 six new experimental ponds were constructed and stocked with many varieties of fish, which grew and did well, and in 1891 two more ponds were formed, both of larger area and deeper than before. From the first of these ponds, constructed in 1890, one hundred and fifty trout, weighing 70 lbs., were served up at a banquet at the Berlin Town Hall in October, 1891. Subsequently the ponds were netted, and yielded in all two thousand five hundred and eighty-eight fish of various kinds. The experiments will be continued for another year, and careful observations will be made on the increase in size and weight of the fish.

G. R. R.

The Kafill Disinfecting Apparatus. By G. Anklamm.

(Gesundheits-Ingenieur, February 29, 1892, p. 105.)

Attention is directed to the importance, according to the present state of knowledge of the influence of micro-organisms, of being able to accomplish their complete destruction in the case of infected animal substances. This is rendered possible by means of the above apparatus, invented by the Director of the Antwerp Slaughter-house. The word *kéfal* signifies in Hebrew to remove, or to take away, and this expression is employed to denote the use of the disinfecting apparatus in disposing of offal, waste animal matter, &c. The machine might indeed be called a carrion-consumer. It has been hitherto a matter of difficulty for the authorities in charge of public abattoirs to get rid of condemned meat and portions of animals unfit for human consumption, many of the present methods of disposal being liable to abuse even under careful supervision. By means of the Kafill apparatus it becomes possible in a few hours, and within the precincts of the slaughter-house, to convert animal substances of all kinds into agriculturally-valuable and inodorous manures. By reference to a diagram the various parts of the machine are explained. It consists in the main of three vertical cylindrical vessels. In the first, which is furnished with a perforated grating near the bottom and is surrounded with a steam-jacket, the carcases, meat, &c., are introduced, and all moisture, gases, fatty matters, &c., are expelled by steam heat. The vapours are condensed in the second cylinder by a cold spray, and any gas or steam escaping from the second cylinder may be further condensed in the third cylinder, which is also furnished with a spray-producer. In working the apparatus, the contents of the first cylinder are gently steamed for about one hour and a half, then all the valves are closed, and under high-pressure steam of from four to five atmospheres (153° to 160° Centigrade) applied for about six hours, all the fat is melted, and, together with the gelatinous matter, it runs to the bottom of the cylinder. The valves are then again opened, and the fat and gelatine are blown over by steam-pressure into the second cylinder, from which they can subsequently be collected. The liquids condensed in the third cylinder are run into the sewers. At the end of the process the bones and fibre of the meat are obtained in a thoroughly disinfected dry state, and merely require grinding in order to form a valuable manure. The fat in the second cylinder is likewise perfectly deodorised and disinfected, and has a commercial value of from 36 to 48 marks per 100 kilograms (18*s.* 3*d.* to 24*s.* 4*d.* per cwt.). The manure sells in Belgium at about 15 marks per 100 kilograms (7*s.* 7*d.* per cwt.) as a dry powder. The average yield from each charge is 25 to 30 per cent. of manure, and from 15 to 20 per cent. of fat. The price of an apparatus to treat 1,200 kilograms at once is set down as 13,000 marks (£650). Analyses are given of the products and data as to expenses of installation, cost of working, &c.

G. R. R.

The Currents of the North Sea. By — PETIT.

(Annales des travaux publics de Belgique, vol. xlix., 1892, p. 477.)

There has been hitherto an almost entire lack of observations on the currents of the North Sea away from the shores, and the Admiralty tide-tables, being founded in this respect on insufficient data, are not to be relied upon in the matter. The present Paper gives the results of a prolonged series of observations made at the lightship "West-Hinder" with a view of supplying this want. The "West-Hinder" is anchored in 17½ fathoms of water (at low tide), about halfway between the mouth of the Scheldt and the Nore, and north by east of Dunkirk. It is, therefore, free from the action of the littoral currents, and is at about the southern limit of the zone of interference of the two tidal waves from the north and from the English Channel.

The results are given in a series of tables, assisted in some cases by diagrams. The observations refer to the speed of the currents; their directions, the duration of flow and ebb, the time of the different phases of the movement referred to the time when the moon is on the meridian, and the effect of various winds on the currents. All these points are discussed at length. In a résumé at the end of the Paper the Author gives the following conclusions.

(1) The direction of the two currents is regular, N.E. ½ E. and S.W. ½ W., when their speed exceeds 1·4 foot per second, and does not vary by more than one point. The reason of this is that the prevailing winds are in the direction of the tidal currents—N.E. and S.W.—and consequently only affect the velocity.

(2) The instant of maximum velocity is variable; at spring-tides it is, on the average, forty-five minutes after the meridian passage of the moon; at neaps it is nearer the meridian passage, and then begins to lag till it reaches one hour and a-half after that period.

(3) The gyratory movement is inverse (*i.e.*, the current changes its direction not by a stop and reversal, but by moving round the points of the compass with a rotation contrary to that of the hands of a clock), and the flow only maintains a considerable speed for some two hours and a-half.

(4) With N.W. winds the flow does not exceed its usual period, but the ebb is variable. With a S.W. wind the speed of the flow may be almost doubled and the ebb feeble, the opposite effect being produced by a N.E. wind.

These general characteristics are liable to unlooked-for variations, arising from the influence of the tidal-wave from the north, of whose effects little is known.

(5) The range of the tide at the "West-Hinder" on the mean of nine years' observations is 13·058 feet, the annual mean varying from 13·442 to 12·697.

(6) A diagram is given of the annual variation of temperature in the sea at the "West-Hinder." The maximum is in the second week of August, and varies from 62° to 65° Fahrenheit. The minimum is at about the end of February, and varies from 35° to 38° Fahrenheit.

C. F. F.

Recently Erected Lighthouses in Finland. By M. STRUKEL.

(Allgemeine Bauzeitung, 1892, p. 4.)

The coast of Finland is a difficult one for navigation, studded as it is with innumerable groups of islets, and far-extending reefs, and for its lighting there are thirty large lighthouses fitted with optical apparatus, seven light-ships with dioptric apparatus, and about forty smaller mineral-oil beacons.

The Author refers especially to the lighthouses erected at Bogskär, Walsöarne, Tankar, Yttergrund, and Jussarö, the positions of which are shown on maps accompanying the Paper.

The most important of these, and that most fully described, is the Bogskär, a rock of small area, situated at the northern end of the Baltic, near where it divides into the Bothnian Gulf and the Gulf of Finland, and lies about 62 miles from the nearest mainland, or 31 miles from the Aland group. There are two rocks, viz., the Eastern and Western Bogskär, about 3 miles apart; it is on the latter that the lighthouse has been erected. The western rock is about 262 feet long and 230 feet broad, with a height of about 13 feet above sea-level, whilst the eastern is 24 feet 6 inches high, but of much smaller area.

The question as to whether the Eastern or Western Bogskär was the better site for a light proved a matter of discussion at various times from 1846 onwards, until in 1878 the western rock was definitely decided upon, and a design worked out for an iron construction resting on a masonry base of 2 feet in height above the rock, or 15 feet above sea-level. Near the tower was to be erected a storehouse of timber, with a connecting corridor roofed with iron. Reference is made to the Eddystone lighthouse, and the inadequacy of such a design as that under consideration for a similar situation. But although the magnitude of the seas occurring in the Baltic is slight as compared with that of the English Channel, the effects of the action of pack ice, in the former instance, have to be allowed for.

As regards the degree of violence of the waves, some idea could be gained from the fact that a masonry column 18 feet in height, erected on the Eastern Bogskär in 1852, to act as a mark during daylight, had continued since that to resist the action of wind and waves without apparent injury. This fact was taken into consideration by the technical commission appointed to consider the design above-mentioned; but the investigation showed that it was not calculated to withstand the wind-pressure. The tower as proposed was formed of an outer and an inner shell, the skeleton of the latter being of twelve cast-iron tee-sectioned members, composed of several lengths connected; by screws, and with a very insecure arrangement for anchorage at the base, and it was recommended by the commission that it should be replaced by a design more in conformity with the ideas of the present day, viz., that the constructive parts throughout should be of wrought-iron, with a thoroughly secure system of anchorage. As, however, the authorities would not relinquish the idea of having the standards of cast-iron, after a modification of the anchorage arrangements had been agreed to, the work was ordered from a Swedish establishment at Ludvigsberg.

The erection of the stone bases of the lighthouse, store, and corridor was commenced in the spring of 1880, and completed by the end of the season, as also was the store, constructed of heavy logs, and the intercommunicating ironwork corridor. In the following spring, it had been intended to proceed with the erection of the ironwork of the lighthouse, which was then ready, but on visiting the site it was found that nothing remained of the superstructure of the storehouse, and only a few fragments of the corridor; the stone bases, however, were uninjured. It was thereupon determined to abandon the idea of constructing a separate storehouse, to raise the height of the foundation masonry to 9 feet 10 inches above the rock, instead of 2 feet, and in heightening the lighthouse base to leave a space forming an arched cellar of 12 feet across, and 7 feet high, to serve as a store for the illuminating oil, &c., and as a refuge in extreme emergency.

The face of the masonry base is vertical, but the tower, formed of an inner and outer concentric shell, is a truncated cone of

67 feet 6 inches high, and 29 feet 6 inches diameter below, and 18 feet 8 inches above. The inner shell is about 22 feet diameter below, and 11 feet 2 inches above, the space of 3 feet 9 inches, left between the shells forming an air-jacket, as a protection against the intense cold of these regions. The tower is divided into seven floors, of which the lowest is the store-room, the next the kitchen, then the living-room, and the following three are bed-rooms, above them being the watch chamber.

The construction, as regards the inner shell, consists of twelve tee-sectioned cast-iron standards, in several lengths, connected by screws, and bolted at the base to the system of cast-iron shoes and anchoring-bolts, built into the masonry base. There are no diagonal wind-ties to these standards, but the wrought-iron rolled joists of the floors, which are carried through to the outer shell, serve as horizontal ties. The outer shell was originally of plate $\frac{3}{16}$-inch thick, without any stiffening other than that given by the wrought-iron floor-joist and the gusset-brackets at the base for attachment to the anchorage. The walls of the inner shell are on the interior clad with $4\frac{3}{4}$-inch planking, and in addition to this is a layer of felt covered with boarding, which forms the lining of the rooms. The spiral stairway is carried between the two shells.

Each apartment has a stove, three windows and a glazed door, with corresponding windows in the outer shell. The light apparatus is of the second order, supplied by the firm of H. Lepaute, of Paris, at a cost of £1,600. The whole cost of the works at the time of completion in 1882, was £12,840. There are from four to six men permanently employed, and the periods for which they are at the lighthouse are six, four, and two months—the six months' term being the winter one.

The tower withstood the weather very well until the year 1889, when, during the night of February 14th, with a gale from the south-west, the waves rose to an unusual height, striking the tower at the height of the first and second floor. The plating forming the outer shell was torn away in the lower portion around the store-room, and the waves washed into the intervening space, the consequent air-pressure causing the whole of the doors to be started, some of the lantern glass and most of the windows to be broken, and the lights to be extinguished. A great part of the outer shell was rent and otherwise damaged as far as the third floor, and most of the provisions in the store were either washed away or spoiled, also the life-boat was carried away. Matters were made worse by the extreme cold, and the freezing of what provisions were left. Attempts were made to communicate with the mainland by a message enclosed in a bottle fixed on a pole in the drift ice, but without effect, and it was not until forty-six days had elapsed that the first steamer passed, and the condition of the keepers was made known. Fortunately no loss of life occurred, and the store being revictualled, the repairs of the damage were at once undertaken. These latter included the substitution of plating of $\frac{3}{8}$-inch (10 millimetres) thick, in place of the $\frac{3}{16}$-inch plate, for the three lowest floors, and stiffening ribs in the outer shell of angle-iron in horizontal and vertical directions, together with a more thorough connection of the tower to the masonry base. The cost of this extra work amounted to about £2,000. In addition to this, there was erected a masonry breakwater on the south-west side of the lighthouse, at a cost of about £640. The probabilities of the sufficiency of this structure for the locality are discussed, and also the effect of the breakwater as constructed. It is proposed to remove the latter, and to reconstruct it farther away, as, at present, from its being so close to the tower, the effect is rather to increase the height of the waves striking the latter. It is also proposed to strengthen the structure by extending the $\frac{3}{8}$-inch plating to the fourth floor, and by riveting bulb-sections to the angle-bar stiffeners. Another proposition for filling the space between the two shells with rammed concrete is discussed, and the possibility of disastrous effects arising, in view of the low temperatures which occur, and the unequal contraction of concrete and of iron.

The Walsöarne lighthouse was completed in 1886. It is situated on an islet—midsea—at the narrows halfway up the Gulf of Bothnia. It is an iron construction, 113 feet high from the ground to the centre of the light, which revolves, and is of the second order. The tower itself is 90 feet 3 inches high, and 27 feet 6 inches diameter at the base, and 9 feet 10 inches diameter above. It is formed of six radial vertical braced ribs, with no outer shell, around a centre wrought-iron plate cylinder of 5 feet 11 inches diameter. Within this is the spiral staircase, and in the centre or axis of tower, a vertical tube of 1 foot 4 inches diameter for the ascent and descent of the weight actuating the revolving-light apparatus. It is anchored into the granite rock, for which purpose holes of 1 foot diameter and 13 feet deep, had to be drilled.

The lighthouse of Tankar was completed in 1889; it is situated near Gamla Karleby, to the north-east of that last described. This structure of wrought-iron takes the place of an earlier one of timber. The height from the ground to the centre of the revolving light, which is of the second order, is 94 feet, and the diameter of the base is 29 feet 6 inches, and above 11 feet 2 inches. It is formed of light, vertical, radial ribs, carrying an outer $\frac{1}{4}$-inch wrought-iron plate shell. In the vertical axis is a wrought-iron tube of 1 foot 4 inches diameter, for the weight of the revolving-light, and also supporting the winding stairway. The weight of wrought-iron in the structure is 95½ tons.

The Yttergrund lighthouse, on the south-west coast of the Bothnian Gulf, near Sideby, is in progress of erection, and expected to be completed this summer (1892). The light is to be a fixed one, and the distance from the ground to its centre 124 feet 9 inches.

The stability of this structure depends almost entirely upon the outer shell, which is composed of wrought-iron plate varying from ¼ inch thickness at the base, to $\frac{5}{32}$-inch at the top, on a framing formed of T-bars, and in the lower portion of channel-bars. Around the interior of this winds the stairway, and in the axis of the tower, assisting in carrying the landings, is a vertical plate tube 1 foot 4 inches diameter. The weight of iron-work in this structure was 89¼ tons, or less than that of the Tankar light, although of far greater height.

The lighthouse of Jussarö, of the second order, was erected in 1890, on a rocky island south of Ekenäs, on the north coast of the entrance to the Gulf of Finland. It is 68 feet 3 inches high, from the ground to the centre of the light, and of about 18 feet 4 inches diameter below, and 14 feet 9 inches above. The tower, formed of a centre column of 2 feet 6 inches diameter, and an outer shell, between which is carried a winding stairway, is of brickwork.

The Paper is fully illustrated by diagrams of each lighthouse.

D. G.

On the Means of Counteracting Droughts.

By GENERAL ANNENKOFF.

(Le Génie Civil, vol. xxi., 1892, pp. 166 and 174.)

The provinces of the east of Russia have suffered from successive droughts in recent years. In 1891 there was a failure of the crops in twenty-one governments with thirty-five million inhabitants. These droughts arise from a gradual change taking place in the climate, which is attributable in a large measure to the disappearance of the forests along the banks of the affluents of the principal rivers, and is also due in part to the removal of obstructions in the rivers for the purpose of facilitating navigation. The same phenomenon has been remarked in many other countries. Rain and melted snow find their way to the sea much more quickly than formerly, and, therefore, a smaller proportion of the moisture is absorbed by the soil. Floods are more violent and more quickly passed, and the low-water level of the rivers is permanently lower than it used to be. The rivers chiefly affected in Russia are the Volga and the Don. The Director of Public Works has decided that measures of two classes are to be taken to remedy the evils above described. First, ponds are to be established in the ravines from which the various affluents of the rivers are fed, retained by small dams, wherever they can be cheaply constructed; and secondly, on the plains long banks are to be formed against which snowdrifts will be formed. The snow thus accumulated will melt more slowly than the thinner covering on the rest of the soil, and will find the ground thawed and absorbent when it does melt. In some parts of Russia, the peasantry have long been in the habit of storing water in this form for drinking purposes.

They use walls of planks to intercept the snow, and it serves them up to the month of August.

The first works for the above purposes are being commenced on certain tributaries of the Don.

C. F. F.

Belt-Carriers and other Machinery for Similar Purposes.

By Hermann Fischer.

(Zeitschrift des Vereins deutscher Ingenieure, vol. xxxv., 1891, p. 924.)

A systematic and scientific treatment of the principles which should govern the proportions and speed of belt-carriers and other machinery intended for similar purposes, has hitherto been wanting. The Author contributes to supply this deficiency in regard to four classes of apparatus, namely: (I.) Elevators (bucket); (II.) Screw-conveyors; (III.) "Wippen"; (IV.) Endless-belts.

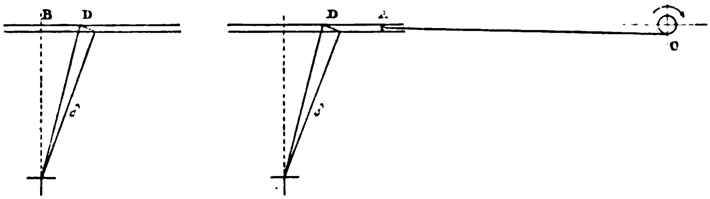
In the case of such machines, there are three main processes:—

(1) The feed;
(2) The actual conveyance;
(3) The discharge.

(I.) *Elevators.*—In estimating the efficiency of an elevator, the following points have to be considered:—

(1) Its capacity; (2) its ability to retain the material lifted to the point of discharge; (3) the circumstances attending the discharge. Let A, *Fig. 1*, represent the centre of gravity of the charge of an elevator-bucket, while passing round the lower pulley

Fig. 1.



of an ordinary elevator, r the radius of the point A measured from the pulley-axis M; m the mass of the charge; g the acceleration due to gravity; ω the angular velocity of rotation of the pulley.

Two forces act on the mass, namely, its own weight $m\,g$, and the centrifugal force $m\,r\,\omega^2$. The resultant R of these forces has the direction GC. The Author shows, by a simple calculation, that the height h of the point G, in which the resultant R intersects the perpendicular line MG, above the centre M of the pulley, depends only on the angular velocity, since—

$$h = \frac{g}{\omega^2}.$$

This also holds good for the upper pulley.

Expressed in terms of the number of revolutions n per minute—

$$h = \frac{91 \cdot 189 \times g}{n^2}.$$

From this it is easy to determine the direction of the resultant R for any speed.

If the contents of the bucket were fluid, the surface at any point would assume a position at right angles to the corresponding resultant force. The materials in question are, however, able to arrange themselves relatively to this position at the natural angle of slope, and the character of the surface of the bucket-contents depends upon the angle which the resultant forms with the radius r of the bucket. Having regard to this point, the Author arrives at the conclusion that the ratio $\frac{r}{h}$ should not exceed 1.

By tracing the relative paths followed by the material discharged from the buckets, for various speeds and dimensions, it is found that the smaller the ratio $\frac{r}{h}$ the greater may be the radial depth of the buckets.

If D = the diameter of the pulleys;
n = the number of revolutions per minute;
a = the radial depth of the buckets measured from the belt surface;
b = the width of the buckets;
t = the length of the buckets in the direction of motion;
M = the quantity of material raised per second in cubic feet;
T = the depth of the edge of the casing, over which the material must be discharged, below the centre of the upper pulley;
w = the clear distance between the walls of the casing within which the elevator works, measured in the direction of the diameter;
A = the power required per second in foot-pounds.

Then the following are the rules given by the Author:—

$a \leqq 0 \cdot 14\ \mathrm{D}$; $r = 0 \cdot 66\ \mathrm{D}$; $\mathrm{T} \geqq 0 \cdot 17\ \mathrm{D}$; $\mathrm{M} = 0 \cdot 18\ b\sqrt[3]{\mathrm{D}}$ (or $0 \cdot 1\ b\sqrt{\mathrm{D}^3}$ cubic metres, when the dimensions are given in metres as in the original); $n = \frac{65 \cdot 2}{\sqrt{\mathrm{D}}}$ (or $\frac{36}{\sqrt{\mathrm{D}}}$ for metric measure); $\mathrm{A} = 1 \cdot 35\ \mathrm{M}\,\gamma\,(\mathrm{H} + 1)$, where γ denotes the weight of a cubic foot of the material.

The values of γ to be used in calculation are for materials in the loose condition in which they fill the buckets.

(II.) *Screw-Conveyors.*—If D denote the diameter of the screw, S its pitch, and l the length; then in most cases $S = 0 \cdot 7\,D$, while for the proper number of revolutions per minute, the Author recommends $n = \frac{45}{\sqrt{D}}$. As a matter of experience it may be assumed that the average cross-sectional area of the material moved is about 42 per cent. of the area corresponding to the diameter of the screw, so that the maximum number of cubic feet conveyed per second—

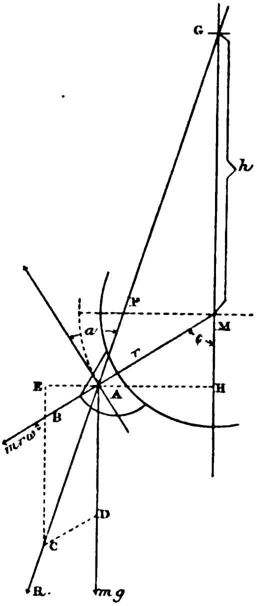
$$M = 0 \cdot 0038\, D^3 n.$$

The power required per second—

$$A = (1 \cdot 35 \text{ to } 1 \cdot 8)\, l\, M\, \gamma.$$

(III.) "*Wippen.*"—Under the name "Wippe," the Author describes a novel kind of conveyor, invented by Mr. E. Kreiss, of Hamburg. This consists essentially of a channel, tube, or rod, AB, *Fig. 2*, in or on which the materials or objects to be conveyed slide, to which is imparted a rapid reciprocating motion by means of a crank C through the connecting-rod CA. The channel, tube, or rod, is supported at intervals by rocking-bars, and has an ascending gradient.

Fig. 2.



The reciprocating action has the effect of imparting to the material placed in or on AB a forward ascending motion. The progress of each particle of material or piece conveyed, is independent of that of its neighbours, so that no pushing or crowding takes place. The mode of action of this apparatus is investigated theoretically by the Author, who is, however, unable to give any practical data.

(IV.) *Endless Belts.*—These possess the advantage that they can be charged or discharged at any point. The discharge, when it occurs elsewhere than over the last roller, is effected by raising the material conveyed sufficiently to allow of its falling laterally into a shoot. The use of inclined sweeps for effecting the same object has been generally abandoned on account of the resulting wear and tear, and also of its inefficiency.

A usual arrangement of an endless belt conveyor is where the guide-pulleys, together with the discharge hopper, are connected to a truck running on rails. This truck can be clamped fast to the rails at any desired point. In this way the position of discharge can be varied. The necessary tension is imparted to the endless belt by means of a weight acting on the end pulley. For the velocity v of the belt, the Author recommends, for light grain about 6½ feet, and for heavy grain about 8·2 feet per second. The radius $\frac{d}{2}$ of the roller over which the discharge takes place should not exceed 15¾ inches for $v = 6\frac{1}{2}$ feet per second, and 23⅝ inches for $v = 8 \cdot 2$ feet per second.

This results from the consideration that the free path of each particle discharged should commence when it lies vertically above the axis of the roller.

Assuming the partitions over the upper edge of which the discharge takes place to be distant $0 \cdot 6\,d$ from the axis of the roller, then the vertical distance of that upper edge above the axis of the roller should not exceed $0 \cdot 3\,d$.

The floor of the discharge-shoot must have an inclination of not less than 45° with the horizontal.

If the surface of the belt is flat, its carrying capacity in cubic feet per second may be estimated at—

$$M = 0 \cdot 03\,B^2 v.$$

If the belt-surface is so supported as to form a curved channel, then—

$$M = 0 \cdot 07\,B^2 v,$$

where B is the breadth of the belt in feet.

For the work expended in driving the conveyor without a load, the Author gives the formula—

$$A_2 = (159 \cdot 9 + 0 \cdot 349\ F)\ 0 \cdot 05\ B^2 v,$$

expressed in foot-pounds per second (or $A_2 = (780 + 5 \cdot 6\ F)\ 0 \cdot 05\ vB^2$ for metric measures), where F denotes the greatest possible distance through which the material can be conveyed on the machine.

The effective work is expressed by $A_n = (1 \cdot 5\ B + 0 \cdot 005 l)\ L\gamma$; (for either English or metric measures), where l is the weight of material conveyed per second, and l the distance it is carried.

G. R. B.

High-Speed Navigation. By J. Gaudry.

(Compte rendu des travaux de la Société des Ingénieurs Civils, April 1892, p. 464.)

The Author examines: 1st, the various types of fast passenger vessels; 2nd, the cost of high speed under present conditions; 3rd, the prospect of the more or less immediate substitution of some new type of propelling machinery for that at present in use.

Full particulars are given of the following vessels: "Touraine," "Normannia," "Teutonic," "City of Paris," "Seine," and "Spree," with an analysis of their best passages. The peculiarities of the construction of the different types, their watertight subdivision, &c., are described, and the dimensions and weight of engines and boilers, the number of engineers and stokers, and other useful details are given.

Under the heading of "The cost of high speed," the variation of resistance with speed, and the effect of dimensions, form, and displacement upon speed are dealt with, and formulas for the determination of indicated HP. for given speeds are discussed, and the realised results obtained with several vessels are compared with them. The last division deals with probable future developments, such as the employment of a metal stronger or lighter than steel, as, for example, nickel-steel or aluminium alloys, improved methods of ship-construction, the introduction of water-tube boilers, increase of steam-pressures, the multiplication of screws, and the like. Consideration is given to the proposals to employ the vapour of volatile liquids in the engines, and liquid and gaseous fuels in the furnaces, and gas and electric motors and hydraulic propellers are not neglected.

S. W. B.

The Statics of Launching.

By Assistant Naval Constructor William J. Baxter, U.S.N.

(Proceedings of the United States Naval Institute, vol. xviii., 1892, p. 67.)

Of the three ways in which a ship may be launched, viz., broadside on, bow on, and stern on, the latter only is investigated.

As the vessel enters the water the centre of buoyancy, or the point through which the supporting force of the water acts, travels from the heel of the sternpost, which is first immersed to a point immediately under the centre of gravity of the ship, which last position is only attained when the vessel is afloat. A "buoyancy curve" can be drawn showing the intersection of verticals through the centres of buoyancy with corresponding water-line. This, together with a displacement curve, enables the displacement and centre of buoyancy to be readily found for any water-line. The weight of the ship acts always through the centre of gravity which does not coincide with the centre of buoyancy as before stated, until she is completely afloat. At intermediate positions there is a couple caused by the weight acting downwards through the centre of gravity, and the upward pressure of the water acting through the centre of buoyancy, and the leverage of the couple is given at any water-line by the distance between the intersection of the buoyancy curve with that water-line, and the vertical through the centre of gravity. The resultant of these two parallel but unequal and opposite forces, will be a force equal to the difference between them acting through a point on the opposite or forward side of the centre of gravity, and at such a distance from it that its moment is equal to the moment of the buoyancy about the centre of gravity, and a "curve of resultants" can be drawn passing through the intersections of the water-lines, with the lines of action of the resultants.

Directions are given for constructing this curve, the origin of which is at the intersection of the water-line passing through the lowest point of the ship with the vertical passing through the centre of gravity, and which has the flotation line as its asymptote. From the "curve of resultants," the pressure on the ways and the line of its action can be readily determined for any water-line. As the ship descends, the water-line rises, the "resultant" becomes smaller, and its line of action moves forward. So long as this remains aft of the forward poppet-lashing, or most forward part of the cradle, the ship will maintain her inclination unaffected, but if it pass forward of the poppet-lashing the ship pivots about its forward support, the stern lifting, and the whole pressure due to the resultant is then concentrated at the poppet-lashing. The ways, poppet-lashing, and ship must be strong enough to resist this pivot pressure, and its value should always be ascertained.

The Author shows how to determine the length of ways necessary to prevent "stumbling" or "tripping." The former occurs when the resultant pressure at any water-line falls beyond the end of the ways. There being then no equal and opposing force, the ship's stern falls, and as she continues to move onward she scrapes against the end of the ways, until the displacement of the after body increases sufficiently to raise the stern, and cause the fore body to strike the ways again. This stumbling often occurs; it is dangerous, and frequently results in serious damage to the ship; in shallow water the stern may strike the bottom, and the launch be a vexatious and costly failure. With a ship whose pivoting-point is some distance aft of the forefoot, another danger may be feared if the ways are so short that the resultant pressure falls beyond them after she has commenced to pivot but before the ship has floated, the forefoot falls striking or scraping the foot of the ways. For a safe launch it is therefore necessary that the ways should be of such ample length that the line of action of the resultant downward pressure shall always fall upon them, and that the pivot shall be supported by them until the ship floats.

The curve of resultants can be accurately drawn, and the pivot-pressure and length of ways determined when the following are known:—

1. The ship's displacement curve.
2. The ship's buoyancy curve.
3. The angle of inclination of the ways.
4. The position of the ship on the ways.
5. The position of the pivot.
6. The weight of the ship.
7. The position of the centre of gravity.
8. The water-level at the moment of launching.

The first five are known months before the ship is launched, but about the remaining three there is more or less uncertainty at the time the calculations are made. It is therefore necessary to assume limits within which they will certainly fall, and allow for the most unfavourable condition. It will be found that for any given position of the ship's centre of gravity the length of underwater ways required will increase when the ship's weight is increased, and for any given weight of ship they will increase when the ship's centre of gravity is moved aft. A less weight of ship with its centre of gravity farther aft usually requires a greater length of underwater ways than a greater weight whose centre of gravity is further forward.

It is therefore sometimes advantageous to place weights in the bow in order to move the centre of gravity forward. Another method of shortening the length of underwater ways is to increase the volume of the afterbody by securing camels, empty barrels, or cork under the counter.

The distance of the line of ways above or below any given point on the ship's side, as the heel of the stern-post, is determined by practical considerations, and does not effect their length.

As a slight fall in water-level requires a considerable increase in length of ways, provision should be made for a fall such as would occur during the first hour after high water.

The greater the difference between the inclination of the keel blocks, and the inclination of the keel after launching, the greater is the pivot-pressure. It is advisable to have this difference as small as practical consideration will permit, and as ships generally draw more water aft than forward they are for this reason usually launched stern on.

S. W. B.

On Smelting the Phosphoric Ore of Gellivara.

(Stahl und Eisen, 1892, p. 490.)

At Finshytte, in Sweden, experiments have been made in smelting the waste ore of Gellivara, which consists chiefly of apatite and magnetite with some rock, and contains from 20 to 25 per cent. of iron, being in fact a ferriferous apatite. In order to prevent the slag from taking up silica by corrosion of the bricks in the hearth and boshes, the lower part of the furnace, to a height of 6 or 8 inches above the twyers, was built of carbon bricks. The ore was for the most part reduced to the size of coarse sand, which rendered the working of the furnace so difficult that pieces of nut size were added to keep the charge open. Only 110 cwts. of unroasted ore were smelted in four days, with air heated to 120 or 150 Centigrade degrees, both alone and with various fluxes of quartz and lime. The best results were obtained without, or with at most 10 per cent. of lime. The slag, which ran very liquid, was crystalline when cooled, and of a grey or greenish colour, with white enclosures consisting chiefly of semi-fused pieces of apatite. The composition was:—

—	A. With ore alone.	B. With 10 per cent. of Lime.
Silica	26·20	21·45
Alumina	4·59	3·62
Ferrous oxide	1·40	0·13
Manganous oxide	0·20	0·28
Lime	43·80	48·15
Magnesia	5·16	5·95
Phosphoric acid	15·48	17·38
Titanic acid	2·30	2·00
Sulphur	0·16	0·21

The proportion of phosphoric acid is fully equal to that in the slag of the basic converter, but the state of combination is somewhat different, only 7·5 per cent. being soluble in citric acid, while in English and German basic slag the soluble part is 14·5 per cent. Both kinds are, however, much more readily decomposed by acid than apatite, and their solubility would probably be increased by using more lime.

The metal corresponding to these slags contained:—

	A.	B.
Phosphorus	10·64	11·86
Combined carbon	0·50	0·65
Silicon	0·08	0·09
Sulphur	0·03	0·02

When tapped it ran very fluid without giving off sparks, and cooled to a silvery white metal, which was very brittle, breaking with a wire-like crystalline structure, and very similar in appearance to ferro-manganese. The composition is a very remarkable one, as, apart from the phosphorus, the analysis is essentially that of a steel.

H. B.

The System of Filling at the Minnesota Iron Company's Mines, Soudan, Minnesota. By D. H. Bacon.

(Advance proof, Transactions of the American Institute of Mining Engineers, Pittsburgh Meeting, 1892.)

The iron ores worked by this company occur in lenses, inclined at 65 to 70 degrees to the horizon, from 200 to 1,000 feet in length, 5 to 80 feet in breadth, and 250 to 550 feet in vertical height. Originally they were worked as open pits to a depth of 180 feet when the yielding of the walls rendered subterranean mining necessary. For this purpose shafts were sunk in the foot wall with the intention of mining the ore by breast stopes in 20 feet lifts followed by underhand stopes of the same dimensions, leaving floors between of the necessary thickness to support the walls or to remove the ore by the stall system. This proved to be impracticable, as the walls of chlorite schist were too weak to allow stopes of 20 feet high, and heavy falls resulted from the hanging and sometimes from the foot wall. But little more than half the ore could be removed by breast stopes, and the cost, owing to the extreme hardness of the mineral, was excessive. A system has, therefore, been adopted of working by lifts from levels 75 feet vertically apart, the excavation being stowed with waste rock as the ore is removed. The levels are carried into the ore as crosscuts from the shaft and turned right and left, the ore being taken away from wall to wall to a height of 15 or 20 feet. When this has been done, drift-setts of legs and cap piece are set up along the entire opening, the necessary spaces, ladderways and air-shoots for mills are close-timbered to a few feet above the drift-setts, and loose rock is run in, filling the space to about 5 feet above the timbers. About 10 feet of the ore overhead is next blasted down, and sent by the mills to tram-cars on the level below. As the stope is extended filling follows, rock being let in, and the passes and ladderways, which measure 5 × 5 feet, are timbered as before. The timbering is close-set crib-work of round timbers flattened at the ends with an interior lining of planks placed vertically, and the bottom is covered with short pieces of rails. There is also an iron spout adjusted for raising or lowering when filling ore into cars. It was thought that the passes would wear out before the ore standing above the level was exhausted; but should this happen the work could be done by converting a ladderway into a mill.

The rock filling is obtained by rises in the hanging, or foot-wall, but usually the former, immediately adjoining the ore body from level to level, and when rock is required in any of the workings the rise below is either filled with rock or stopped with timber to prevent the stuff falling below the place at which it is received, and where it is received in tram-cars. The system has been in use for two years, and has proved satisfactory. In the winter when the superincumbent rock is frozen, it has been found possible to remove nearly all the ore in the upper levels, and after the first level is exhausted, rock is taken from it to fill the spaces below. Any filling that may be required before the level next above is exhausted is supplied from accumulated loose stuff in the open pit, or by blasting in the sides of the latter; but in narrow veins it is sometimes obtained by breaking down the walls underground. One advantage of the method is that the rock broken from the walls or from seams in the ore is left almost in the place where it falls, causing no expense for tramming or hoisting, and often none for throwing it to one side.

For the local conditions the system appears to be better than that adopted at Rio Tinto mines, as described by Mr. Delprat, as the expense of lowering rock is avoided, excellent ventilation is secured, and no rock drifts or cross-cuts, other than one to the shaft at each level, are required. Experience has shown that back stoping is cheaper than underhand. The roof is always near and can be easily examined, and as the mills are seldom more than 50 feet apart, the trammers can work at a pile of ore from either side without either delaying the miners or standing under ground that has not been made safe.

When the ore body is very wide it has occasionally been necessary to leave small pillars on the hanging-wall side, but the loss from these is but slight. Slabs in the back are often temporarily supported by cribs of timber built on the filling, and wedged tightly; holes are then bored in the slabs, the cribs are removed, and the dangerous rock is broken down. The timbers are used for the same purpose in other places, and to extend the footways and passes.

In addition to the ordinary footway in the shaft, rises are put through the rock from level to level, about midway between the ore body and the shaft, and fitted with ladders to form an escape in the event of fire.

It has not been found necessary to select particularly large timbers for the drift setts, or to place them very close together, and in some of the levels none of the timbers have broken under a load of 80 feet of rock.

The Paper is illustrated by a complete series of plans and sections, showing the application of the system to the removal of an ore deposit about 80 feet wide and 500 feet deep on the incline.

H. B.

On the Uniformity in Composition Attainable in Basic Mild Steel. By H. MEHRTENS.

(Stahl und Eisen, 1892, p. 593.)

In the construction of the new bridge over the Vistula on the railway from Bromberg to Culmsee, a work extending over many years, more than 10,000 tons of steel will be used, the manufacture of which has been entrusted to three firms—the Harkort Company in Duisburg working in combination with the Aachen Smelting Company of Rothe Erde, and the Guttehoffnung Works at Duisburg; the basic open-hearth furnace being used at the latter works, and the basic Bessemer converter at Rothe Erde. The system of testing is a very elaborate one, each heat being subject to investigation as to the composition, strength, and working qualities of the metal at different stages between the end of the blow to the final rolling. From each heat bars from three different ingots were tested, and the phosphorus, manganese, and carbon determined, while from every tenth heat the tests were extended to five bars, and silicon and sulphur were determined in addition. The mechanical tests, which are of the usual kind, are represented in a reproduction of a photograph of the results of one set, including fifteen different specimens, and the paper gives a general summary of the results hitherto attained.

Up to the 1st of May tests had been made at Rothe Erde of three hundred and thirty-six heats, representing about 3,100 tons of finished material without any rejections, three hundred and twenty-three of them being of plates and bars of various sections for structural use, and thirteen of rivet-iron. The extreme limits were in tons per square inch.[1]

——	Elastic Limit.	Tensile Strength.	Elongation.
Sections.			Per cent.
Highest	15·81	24·89	20·0
Lowest	20·69	27·80	32·5
Rivets.			
Highest	16·57	24·10	25·2
Lowest	18·15	24·70	28·7

The different values obtained and their proportion to the total are tabulated as follows, each representing the mean value of the different results in each heat:—

BASIC BESSEMER METAL.—A.—323 HEATS.—STRUCTURAL IRON.

Elastic Limit. Tons per Square Inch.	No. of heats.	Per cent.
15·81—16·51	16	4·96
16·51—17·14	53	16·40
17·14—17·78	131	40·57
17·78—18·41	72	22·29
18·41—19·05	31	9·58
19·05—19·68	15	4·65
19·68—20·32	3	0·93
20·32—20·69	2	0·62
..	323	100·00

Tensile Strength. Tons per Square Inch.	No. of heats.	Per cent.
24·89—25·40	39	12·06
25·40—26·03	128	39·65
26·03—26·68	90	27·87
26·68—27·30	55	17·02
27·30—27·80	11	3·40
..	323	100·00

Elongation. Per cent.	No. of heats.	Per cent.
21—22	1	0·30
22—23	0	0·00
23—24	3	0·92
24—25	5	1·54
25—26	24	7·43
26—27	62	19·21
27—28	74	22·92
28—29	77	23·85
29—30	52	16·11
30—31	20	6·19
31—32	4	1·23
32—32·5	1	0·30
..	323	100·00

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[1] These have been reduced from the values given in kilograms per square centimetre in the original.

BASIC BESSEMER METAL.—B.—13 HEATS.—RIVET IRON.

Elastic Limit. Tons per Square Inch.	No. of heats	Per cent.	Tensile Strength. Tons per Square Inch.	No. of heats.	Per cent.	Elongation. Per cent.	No. of heats.	Per cent.
16·57—17·14	4	30·77	..	..	..	25·2—26·0	4	30·77
17·14—17·78	7	53·85	..	..	..	26·0—27·0	3	23·05
17·78—18·15	2	15·38	..	..	..	27·0—28·0	4	30·76
						28·0—28·7	2	15·39
..	13	100·00	24·10—24·70	13	100·00	..	13	100·00

Chemical composition—

		Per cent.
In the 336 heats	Phosphorus varied from . .	0·031 to 0·085
	Manganese „ . .	0·260 „ 0·790
	Sulphur „ . .	0·017 „ 0·071
while the maximum of	Carbon was	.. 0·110
and of	Silicon	.. 0·020

The variation by heats and percentage being—

Phosphorus.			Manganese.			Sulphur.		
—	No. of heats.	Per cent.	—	No. of heats.	Per cent.	—	No. of heats.	Per cent.
0·03—0·04	16	4·7	0·2—0·3	4	1·1	0·01—0·02	1	2·6
0·04—0·05	48	14·3	0·3—0·4	49	14·6	0·02—0·03	5	13·3
0·05—0·06	62	18·4	0·4—0·5	137	40·7	0·03—0·04	11	28·9
0·06—0·07	94	28·0	0·5—0·6	114	33·9	0·04—0·05	11	28·9
0·07—0·08	83	24·7	0·6—0·7	27	8·3	0·05—0·06	7	18·4
0·08—0·085	33	9·9	0·7—0·8	5	1·4	0·06—0·071	3	7·9
..	336	100·00	..	336	100·00	..	38	100·00

In the testing of three hundred and sixty-eight heats of basic open-hearth metal at Gutehoffnungshütte, thirty-seven showed defects requiring them to be repeated, and on second testing thirteen of these were finally rejected on the following grounds: four for excessive hardness, one for deficient elongation, five for deficient tenacity, two for cinder patches, and one for blow-holes. In addition one heat was rejected for too high tensile strength (29·76 tons).

The following Table shows the data for the accepted heats arranged in the same manner as the preceding one.

BASIC OPEN HEARTH METAL.—A.—STRUCTURAL IRON.—355 HEATS.

Elastic Limit. Tons per Square Inch.	No. of heats.	Per cent.	Tenacity. Tons per Square Inch.	No. of heats.	Per cent.	Elongation. Per cent.	No. of heats.	Per cent.
15·36—15·87	11	2·11	24·89—25·40	21	5·91	20·5—21	2	0·57
15·87—16·51	28	7·89				21—22	3	0·84
						22—23	13	3·66
16·51—17·14	57	15·97	25·40—26·03	99	27·90	23—24	13	3·66
						24—25	27	7·61
17·14—17·78	66	19·69				25—26	27	7·61
						26—27	38	10·70
17·78—18·41	71	20·00	26·03—26·68	97	27·32	27—28	45	12·68
18·41—19·05	49	13·80				28—29	44	12·40
						29—30	44	12·40
19·05—19·68	41	11·55	26·68—27·30	77	21·69	30—31	43	12·11
						31—32	23	6·48
19·68—20·32	14	3·93				32—33	16	4·51
						33—34	10	2·81
20·32—20·95	7	1·97	27·30—27·94	37	10·42	34·5	1	0·28
20·95—21·20	4	1·12				35·0	3	0·84
						36·0	1	0·28
21·59	1	0·28	27·94—28·57	24	6·76	36·5	1	0·28
Missing	6	1·69				37·0	1	0·28
..	355	100·00	..	355	100·00	..	355	100·00

BASIC OPEN HEARTH METAL.—B.—RIVET IRON.—11 HEATS.

Elastic Limit. Tons per Square Inch.	No. of heats.	Per cent.	Tenacity. Tons per Square Inch.	No. of heats	Per cent.	Elongation. Per cent.	No. of heats.	Per cent.
15·00—15·23	1	9·08				26·0—27·0	5	45·46
15·23—15·87	1	9·08	23·18—23·80	3	27·28	27·0—28·0	1	9·08
15·87—16·51	0	0·00						
16·51—17·14	4	36·39	23·80—24·45	4	36·36	28·0—29·0	1	9·08
17·14—17·78	3	27·29				29·0—30·0	2	18·19
17·78—18·41	1	9·08						
18·41—19·52	1	9·08	24·45—25·20	4	36·36	30·0—30·8	2	18·19
..	11	100·00	..	11	100·00	..	11	100·00

The results of the chemical investigation showed that—

In 366 heats phosphorus varied from . . . . . 0·030 to 0·070
„ 366 „ carbon „ „ . . . . . 0·100 „ 0·140
„ 64 „ manganese „ „ . . . . . 0·355 „ 0·500
„ 56 „ sulphur „ „ . . . . . 0·040 „ 0·080
Silicon was not determined.

Phosphorus.	Heats.	Per cent.	Carbon.	Heats.	Per cent.
0·030—0·040	120	32·79	0·100—0·110	123	33·61
0·040—0·050	97	26·50	0·110—0·120	102	27·87
0·050—0·060	136	37·16	0·120—0·130	101	27·69
0·060—0·070	13	3·55	0·130—0·140	40	10·92
..	366	100·00	..	366	100·00

Manganese.	Heats.	Per cent.	Sulphur.	Heats.	Per cent.
0·355—0·400	11	17·2	0·04—0·05	25	44·64
0·400—0·500	53	82·8	0·05—0·06	16	28·58
			0·06—0·07	10	17·86
			0·07—0·08	5	8·92
..	64	100·00	..	56	100·00

H. B.

The Yield of the Ilsede Blast Furnaces in 1891.

(Stahl und Eisen, 1892, p. 399.)

At the Ilsede works, where highly phosphoric white pig-iron for the basic Bessemer process is smelted from manganiferous brown ores mixed with phosphorite, the three furnaces in blast during the year made the following quantities in tons of 1,000 kilograms :—

	Days.	Tons.	Tons daily.
Furnace No. 1, blowing	73	10,737,	or 147·08
„ „ 2, „	365	68,193	„ 186·83
„ „ 3, „	295	55,341	„ 187·60
Total	733	134,271	„ 183·18
In 1890	730	128,732	„ 176·35

Showing an increased yield of 6·83 tons per furnace per day. The materials used were :—

	Tons.	Tons per Ton of pig.
Ores	372,196	2·772
Coke	126,206	0·940
Coal	3,022	0·023

Burden smelted per ton of coke, 2·95 tons ; yield of ore 36·08 per cent.

The consumption of fuel in the year, 940 kilograms per ton, was notably higher than in the two preceding years—922 kilograms in 1890, and 899 kilograms in 1889. This was due to the inferior quality of the coke purchased.

The ores were delivered to the furnaces at a cost of 2*s.* 2½*d.* per ton, and the prime cost per ton of pig-iron was about £1 12*s.* 1*d.*

Furnace No. I was blown in on October 20th, and two days later No. III was put out of blast after blowing continuously for seven years and twenty-two days, during which time it made 414,985 tons, which is probably the largest quantity ever produced from a single lining. This furnace, although only 58 feet high and of 10,980 cubic feet capacity, has as a rule made more iron than No. II, which went into blast in September, 1892, and is 66½ feet high and 15,926 cubic feet capacity.

H. B.

The Marsac Refinery, Park City, Utah. By C. A. STETEFELDT.

(Advance proof, Transactions of the American Institute of Mining Engineers, Lake Champlain Meeting, 1892.)

The establishment described in this Paper is engaged in the reduction of the silver sulphide precipitates obtained in the treatment of silver ores by the Russell process of lixiviation with sodium and copper hyposulphites, which has been previously noticed.[1] The precipitates obtained are of three kinds, known respectively as: (1) Base sulphides obtained from the wash-waters by sodium sulphide; (2) Carbonates obtained from the hyposulphite liquors by sodium carbonate; and (3) So-called regular sulphides obtained by sodium hyposulphite after all matters separable by sodium carbonate have been removed. Their average composition is as follows:—

——	Ounces of Silver per Ton.	Copper.	Lead per Cent.
Base-Sulphides . . .	2,200–5,200	2·6–5·2	38–45
Carbonates	600–1,400	..	23–41
Regular Sulphides . .	11,200–12,000	23–28	0–1

The carbonates contain 1·6 to 3·9 ozs., and the regular sulphides 11·1 to 12·1 ozs. of gold per ton. No complete analysis of these precipitates has been made, but the first two are known to contain lime, and probably from 10 to 13 per cent. of soluble salts, as they are not washed in the filter-press. Both kinds of sulphides contained free sulphur in considerable quantity. As the base sulphides and carbonates contain lead, they are sold to smelters, and only the regular sulphides, which however contain 87 per cent. of the silver produced in the mill, are treated on the spot, by the following series of operations :—

1. Fusion for regulus.
2. Roasting in muffle furnace.
3. Digestion in dilute sulphuric acid.
4. Removal of copper as sulphate by crystallizing.
5. Washing, pressing, and melting of silver precipitate.

1. *Fusion.*—This operation is necessary on account of the large amount of free sulphur in the precipitate, which interferes with direct calcination. It is performed in a cast-iron pot 3 feet by 2 feet at the top, 11 inches deep, tapering in thickness from 2 inches at the bottom to 1 inch at the top, which is set in a fireplace and covered by a hood of sheet-iron with a working-door. The draught is so regulated that the flame is smoky, to prevent the cast-iron from burning. Fusion takes place at a very low red heat, and the product is very liquid. In the laboratory experiments the best results were obtained when copper and silver were present in about equal proportions, but on the working scale it is not found necessary to add copper if the subsequent roasting is carefully done. If much copper is added the fusion is often incomplete, part of the charge coming out in semi-fused, partly oxidized lumps, but ordinarily the product is perfectly well melted. It is cast into sheets about ¼-inch thick in a cast-iron box, and becomes perfectly brittle when cold, although while still hot it is so flexible that the sheets can be rolled up like sheet-lead. On account of the great affinity of copper for sulphur, the cast-iron pot and the tools used in the operation are not attacked by the melted sulphides, and pieces of wrought-iron, which are occasionally introduced when cement copper is added, are also unchanged.

About 800 lbs. of sulphides are melted in twelve hours, with an expenditure of 200 lbs. of coal; 15,000 lbs. of sulphides have been melted in one pot before it commenced to leak.

The gases from the melting-pot, as well as those from the calciner, are drawn by a Körting aspirator through a Roëssler converter, with a view to the conversion into sulphuric acid for use in the process; but this operation has not been a success, as the acid obtained is too low in concentration, and too small a quantity to be of much practical value. The apparatus, however, acts as a fume-condenser, and the acid liquor after filtration is pumped to a wash-water tank.

2. *Roasting.*—The melted sulphides when perfectly cold are ground in a Brückner ball-mill to pass a 40-mesh screen. The product, which is scaly and granular and absolutely free from dust, is calcined in a muffle furnace heated from the top only. The oval bed of this furnace is 7 feet long by 4 feet 6 inches wide, having a cast-iron bottom-plate 1½ inch thick, with a rim 1½ inch high. There are two working-doors on opposite sides, and air is introduced by a slit between them and the fireplace, which is

arranged for burning coal with a grate 3 feet 6 inches long and 18 inches wide. The gases from the muffle pass to the Roëssler converter by 4-inch iron gas-pipes, which are cooled externally by water-spray, in order to prevent damage to the Körting blower, made of hard lead. The charging is done through the working-doors, and the finished charge is dropped by a hole 6 inches square in the middle of the bed, closed by a well-fitting iron plate into a car below. The charge of 600 lbs. is added, half at the commencement and the remainder at intervals after the first portion has taken fire, which happens when the furnace is properly hot, in fifteen or twenty minutes after charging. During the desulphurizing very little fire is needed, but later on the heat is increased. About 1,000 lbs. of coal are burnt during the eight hours' roasting.

The charge is drawn when a sample dropped into a bucket of hot water looks black, shows a weak spangle reaction (from the reduction of silver sulphate by cuprous oxide), and gives a copious precipitate of silver chloride by hydrochloric acid. The small lumps, when broken, should not show red kernels of cuprous oxide. The roasting, unlike that in the Ziervogel process, is not intended to produce a high proportion of silver sulphate, and the charge after roasting, when heated with dilute sulphuric acid, rarely shows any dissolved silver, the sulphate being decomposed by the cupric oxide present.

3. *Dissolving.*—The roasted material when cooled, is ground in the ball-mill to the original degree of fineness, and treated in quantities of 300 lbs. in lead lined vats, containing 16 cubic feet of acid, mother liquor from the blue vitriol crystallizer, to which sufficient strong acid has been added to give 2 lbs. of H_2SO_4 for every pound of copper present. The liquor is first brought to a boiling heat by steam, and the charge is slowly shovelled in, the boiling being continued for two hours. Copper plates are suspended in the solution to precipitate any silver that may not be reduced by the cupric oxide, but the wear of these plates is only very slight. The second crushing was found to be necessary, as when the roasted material was only sifted through an 8-mesh screen the solution was imperfectly effected, and hard crusts formed on the dissolving tanks which had to be removed by chisels, but when ground to pass a 40-mesh the charge is easily dissolved and comes out perfectly clean.

Filtration.—The acid liquor, containing copper salts in solution and precipitate silver in suspension, is run through the conical bottom of the tank into a filter-press, where the precipitate is collected upon lead plates lined with asbestos cloth. A Körting pump is placed below the filter, but is not used until the bulk of the solution has passed. It is necessary to perform the operation rapidly, in order to prevent the copper-salt from crystallizing out, and this circumstance has prevented the separation of the silver by settling and decantation as much of it is so fine that the settling requires a long time, and the solution became so cold that crystallization set in before the separation was effected. The copper liquors are usually at a density of 42° to 43° Beaumé; when stronger they can only be filtered with difficulty.

4. *Crystallizing.*—The solution from the preceding operation, when hot, contains a cuprous salt, as shown by the precipitate of cuprous chloride, when a drop of hydrochloric acid is added, but on cooling it is decomposed into cupric sulphate and metallic copper, which deposit together in the crystallizers, and when the blue vitriol crystals are very small they appear almost white, blue and red being complementary colours. The crystallizing vats measure 6 feet by 3 feet deep, are lined with sheet-lead, extra depositing surface being afforded by forty-eight strips of sheet lead 3 inches wide and 20 inches long, suspended on each. The salt is deposited very rapidly, as showy crystals are not required, most of the product being used in the works for making extra solution, for which purpose small crystals are better than large ones. When the density of the mother liquor is reduced to 30° Beaumé, in which state it contains about 8 per cent. of free sulphuric acid, it is returned to the dissolving tanks, and continues to circulate between the two processes without change of volume, until by the increase of ferrous sulphate and other impurities, it becomes fouled, when it is pumped to the precipitating tanks. There are two of these, each 6 feet long, 2 feet wide, and 4 feet deep, lined with lead, divided into four compartments with a V-shaped bottom and a grate upon which the scrap-iron rests. The solution is circulated by a Körting pump, and the fine precipitate copper falling through the grate collects at the bottom and is discharged through gates on the V-shaped ends into a filter-car. The precipitate usually contains silver from the turbid solution drawn from the Roëssler condenser, which is added as well as the wash-water from the silver. The whole of the copper is returned to the sulphide melting furnace.

5. *Treatment of the Precipitate Silver.*—When six charges of silver have accumulated in the filter-tank, about 6 inches of water are run on the top and circulated until the specific gravity of the liquor is constant at 20° to 22° Beaumé, when it is discharged to the crystallizer. The washing is then continued with fresh water, giving liquors for the weak solution tank, and afterwards until the density is only a fraction of a degree, the water going to the copper precipitating tanks.

The operation is suspended when the addition of a few drops of ammonia only gives a faint blue colour.

The washed silver, being rather too moist for pressing, is put into a drier heated by air from the iron chimney of the muffle furnace. This is an air-chamber formed round the chimney by a mantle of sheet-iron, through which hot air is drawn by a Körting aspirator. When the bulk of the moisture has been driven off, the precipitate is moulded by a pressure of 1,000 lbs. on the square inch, into cylindrical cakes 6 inches in diameter and 4 inches thick, weighing about 9 lbs. each. These are put back into the drier, and subsequently melted and cast into bars. The latter average from nine hundred and forty to nine hundred and fifty fine, but it is expected that a higher fineness will be obtained. The gold goes with the silver.

The refining, which is carried on in the daytime only, employs two men and a boy; one of the former attends to the melting and the other to the dissolving operations. The boy works the pulverizer and the cake-press, and makes himself generally useful. For melting silver an extra man is employed.

The refinery is contained in a main building 52 by 42 feet, and an annex 52 by 25 feet, containing the sulphide drier, ball-mill engine, cake-press, sample-grinder, and storage for acid, coals, and sulphides. The silver-melting is done in the former retort-room of the amalgamation mill.

The whole building is provided with a floor of cement concrete, upon which every speck of dropped sulphides or regulus can be seen.

The estimated cost of refining an output of about 2,000 ozs. of silver per day, is $1,430 gross per month, or $874, allowing for value of copper sulphate returned and sold. When the sulphides are sold to melters the returning charges, freight, and loss, on the average amount to $2,231 for the same quantity, leaving a margin of $1,357, or about 2·52 per cent. on the silver contained in the sulphides in favour of refining. The actual loss of silver in the process has not as yet been accurately determined. The Author considers that the melting would be improved by moistening the cake-silver with a strong solution of borax, and substituting a small reverberatory furnace for crucibles.

H. B.

Report of the Royal Commission on Gold Mining, Victoria, 1891.[1]

On the 15th of July, 1889, a Royal Commission was appointed to report as to the best mode in which assistance could be rendered to develop the auriferous resources of the Colony of Victoria. The report, which covers 1,025 pages, was signed on the 30th of September, 1891; it deals with every branch of gold-mining.

Auriferous areas.—A vast amount of information relating to the auriferous resources of Victoria has been brought together, the geographical distribution of the ores, and the mode of occurrence of the gold being fully dealt with. Many districts, some of which are of large area, are known to contain gold, but as yet have been only imperfectly explored. A description is given of several such districts which are suitable for State-aided, or private exploration.

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[1] The original is in the Library of the Inst. C.E.

For the purpose of prospecting, small government grants have been made; but this method of expending public money is condemned by the Commission, who recommend that the grants should be larger, and should be given only in cases of national importance where private enterprise is unavailable. The grant should thus be devoted to some important work, such as sinking a shaft, or driving an adit-level in a central situation in a promising district. Much exploratory work is being done by diamond drills. The cost of boring, as deduced from the prospecting vote is given at 12*s.* to 14*s.* per foot. Other estimates give the cost at 16*s.* 3*d.* to 17*s.* 8*d.* Some 216,834 feet have been bored, and the number of bore-holes amounts to 1,016, the deepest being down 1,506½ feet, and the longest diagonal bore being 723 feet at 30° at the end of a tunnel. The cost of diamonds is 30*s.* to 90*s.* per carat, according to quality. The large areas that can be explored by the aid of diamond drills causes this method of prospecting to be regarded very favourably. Another method of developing the resources of the colony, and one that appears to be of value, is track-cutting. This should be largely done at public expense to aid in the transport. The sections exposed in this way would render evident the geological structure of the country. A map should be prepared showing the main physical features of the colony, and the geological survey should be pushed forward.

Mining.—In studying the mining appliances in use, the Commission have examined four dredging-plants at work in various parts of the colony. One of these works as a dredger, whilst the others are constructed on the suction principle. The working plant is carried on a barge, and cuts its passage by means of a centrifugal pump, which sucks up the gravel in front, and discharges it over gold-saving appliances. The blades of the pump are exposed to great wear; but in the Ballarat plant they can easily be replaced. There is also some difficulty with the gold-saving appliances on account of the limited space available, and there appears to be room for considerable improvement in this direction. It is not clearly determined whether dredging-machines will take up all the gold from the bed, or whether it will be necessary to clear up the ground a second time. In either case there appears to be a large field for the application of these machines, especially in re-working exhausted deposits.

With regard to the use of explosives, a large amount of evidence has been collected. The prevailing practice of mixing dynamite and gunpowder in one charge is condemned as dangerous and wasteful. In order to secure perfect combustion, which is absolutely necessary, smaller charges properly proportioned to the work to be done should be used. The employment of excessive charges appear to be common. Electric methods of firing are recommended, especially in sinking-operations. Gelatine explosives are considered the best in water; but where displacement, and not disruption, is required, gunpowder, dynamite, or rackarock are preferable. The cartridges should fit the bore-hole, and the tamping-bars should be of wood and not of copper. The miners should not be allowed to have unlimited command of explosives, and not more than a week's supply should be stored underground.

In order to maintain the supply of mine-timber, the reservation of worked-out mining areas for replanting is insisted on. In accordance with the suggestion of the Commission, the Forestry branch has already been affiliated to the Mining Department. One witness recommends the blue gum, iron bark, stringy bark and jarrah as suitable for cultivation, and incidentally describes what is known in South Australia as the "bamboo system" of forestry. In this system the seeds of the trees to be grown are planted in short lengths of bamboo placed vertically in the ground, and filled with earth. The bamboo causes the roots to strike downwards, and a tap root is formed, which is very necessary when the trees are to be grown in a more or less arid district.

Winding-engines should, it is considered, in all cases have double cylinders, and great economy would result from the use of compound condensing engines. Winding drums and pulleys of large diameter, and wire ropes should be employed.

With regard to water-supply and mine-drainage, dissatisfaction with the existing law is expressed, and it is urged that public funds should be applied to the construction of reservoirs and water-channels, and also to aid in the drainage of districts where the amount of water is great, or where old workings, containing much water, are being approached.

For ventilating mines, the natural system is undoubtedly the best; but in many instances it is very defective. Especially is this the case in old mines where the workings have gradually extended so that they cannot now be properly arranged except by driving extra winzes and levels at great expense. If no other method is applicable, adjacent mines should be connected, so that one shaft should form the upcast, and the other the downcast. Artificial ventilation may be on the exhaust or on the injection principle. Either system has its defects. The main object, however, is to obtain not a strong draught, but a good steady current of air that is made to reach every part of the mine. The air, too, must be kept pure by stripping the bark from the timber, and by removing all unnecessary organic matter from the mine.

Metallurgy.—The prevailing methods of metallurgical treatment of gold ore are fully described, and suggestions are made as to improvements that may be effected. With regard to gold-saving appliances, the use of mercury wells with 8- to 9-inch drop is recommended in place of shallow riffles. The blanket strakes or concentrating screens should be placed below the plates, and above the percussion tables. The evidence clearly shows that there is much loss of the sulphides in the tailings owing to the imperfect ore-dressing machinery employed. To this main cause the decrease in the gold production of Victoria is attributed. The present mode of concentration used in some batteries might be made more effective by sizing the ore by means of revolving trommels of different meshes before delivering the pulverized material on to percussion tables, and by erecting at the end of them jigging machines if required, and Frue vanners, or classifiers, and rotating slime tables. Dry concentration has been attempted, but the evidence is not conclusive as to the practical value of this method. Importance, however, is attached to it for districts at high altitudes where work can only be carried on in the summer when the water is scarce. For the extraction of gold from the concentrates, three methods have been adopted:—amalgamation, chlorination, and smelting. No accurate details of the loss in these three methods are available; but, taking into account the keen competition for amalgamating concentrates, it is reasonable to assume that the result obtained is close to the assay value of the ores, and that the three processes, from a technical point of view, are satisfactorily worked. In some cases, the concentrates are amalgamated in their raw state, but the more usual practice is to submit them to a preliminary roasting. Particular attention is directed to the large number of heaps of tailings scattered about the country, and a large number of assays were made, showing from a trace to over half an ounce of gold per ton. Several attempts have been made to treat these tailings, but hitherto without marked success. One solution may be found in a cheaper method of roasting, in which the sulphur in the pyrites will serve as fuel, and in subsequent amalgamation or chlorination. The cyanide process is also described, and it is proposed that a premium should be offered for the best system of gold extraction.

Health and Education of Miners.—With a view to insure healthful conditions underground, rules should be formulated, and rigidly adhered to. The law relating to changing-houses should also be strictly enforced. Such houses should be provided with a fireplace, shower-baths, and steam-pipes for drying purposes. In case of an accident, these houses are of inestimable value.

There are several mining schools in the colony. They are doing good work, and the Commission are of opinion that every reasonable facility should be given to aid them in training skilled men. No perfect collection of minerals and rocks exist. These should be made and opened to the public as soon as possible, as they would be of great value to the working miner. As another effective method of aiding mining, premiums should be offered for inventions, new appliances, discoveries, and new marketable products.

B. H. B.

A New Method of Assay of Antimony Ores. By A. Carnot.

(Annales des Mines, vol. i., 1892, p. 303.)

The ordinary dry way of assaying antimony ore by fusion with soda charcoal and metallic iron, gives a very inaccurate idea of its metallic contents, the Author having found differences from the results obtained by analysis which are rarely below 8 or 10 per cent., and in the case of poor minerals may be as high as 20 or 30 per cent. After many attempts to improve the process which have not proved successful, owing to the volatility of antimony, the Author has abandoned the dry method of assay, and substitutes a method of solution and precipitation of the metal by tin, which gives very satisfactory results. In dealing with sulphide ores, from 2 to 5 grams of the finely powdered mineral is heated with 50 to 60 cubic centimetres of strong hydrochloric acid, but not allowed to boil. When the action ceases the liquid is decanted, and fresh acid is added until the sulphide is entirely decomposed, a few drops of nitric acid being sometimes added towards the end, and the insoluble matter is washed clean with water. The several acid solutions are united, diluted with an equal volume of water heated to 80 or 90°, and a plate of tin is inserted. The precipitation of the antimony commences at once, and is completed, when the quantity is about 1 gram, in one and a half hours. The precipitated metal is washed by decantation, digested with weak hydrochloric acid to remove tin salts, and is finally collected in a tared filter, washed with water and alcohol dried at 100°, and weighed. The error of the result as determined by experiments upon mixtures of native sulphide of antimony and quartz is below 1 per cent. on the amount found by more exact analytical methods.

In the assay of oxidized ores which are usually mixed with unchanged sulphide, there is often considerable difficulty in getting the antimony completely dissolved, and there is a further chance of loss by volatilization. This may be avoided by converting the oxidised minerals into sulphide by passing a current of dry sulphuretted hydrogen through it. This is done by exposing about 5 grams of the mineral, forming a thin layer in a flat-bottomed flask to the action of sulphuretted hydrogen dried by chloride of calcium, which is introduced from a bent tube nearly touching the layer of mineral. The flask is placed on a piece of wire gauze about 2 inches above the flame of a Bunsen star burner, so that the temperature may not exceed 300°. The gas first reduces the oxide and then converts it into sulphide, a small quantity of oxide and sulphur being produced which condenses in the cooler part of the flask, but there is no loss of sulphide of antimony. The operation is complete in about an hour, and the solution is effected in the manner described above.

Iron and zinc have no effect upon the accuracy of the result; but when the ore contains lead that metal is partly precipitated as chloride, while part remains in the rotunda, and is deposited in the metallic state upon the plate of tin. This may be estimated in the weighed metallic precipitate by heating it to 50° or 60° in a solution of sodium persulphide (formed by boiling sodium monosulphide with flowers of sulphur) when the antimony is rapidly dissolved, leaving a residue of lead sulphide containing 86 per cent. of lead. As, however, there is invariably some oxidation during the drying of the precipitate, the surcharge will be somewhat greater, and 90 per cent. of the weight of the sulphide may be taken to be the proper correction to be made for the lead present. Arsenic, when present in the ore, is precipitated with the antimony, and its presence can be determined qualitatively, but no method of estimating the quantity has been devised. This, however, is of less importance, as arsenical antimony ores are comparatively rare.

H. B.

Progress of the Metallurgy of Nickel.[1] By D. LEVAT.

(Annales des Mines, vol. i., 1892, p. 141.)

Nickel is found in New Caledonia in a single mineral, Garnierite or Noumeite, a hydrated silicate of nickel and magnesium, of a bright apple-green colour when pure, which is deposited in concretionary masses, or cratings, in the fissures of a serpentine rock. This silicate is not a product of secondary decomposition, no traces of sulphides or arsenides of the metal having been found even in the deepest workings, and the mode of occurrence indicates clearly that the mineral has been deposited by water in the form in which it is now found. In a collection of specimens brought to Paris by Mr. Peletard, an engineer who has lately published a geological map of the island,[2] impressions of insects have been found which are referred to living forms. The distribution of the mineral through the serpentine matrix is not an arbitrary one, it being always found at or near the contact of the rock with the red clays, filling basins or cavities in the rock, but never in the clay itself. These masses of clay are products of the decomposition of the serpentine, and contain all its constituents, in addition manganese, cobalt, and chromium. The thermal springs that have given rise to these clays follow lines of fissure having a general N.E. and S.W. direction. These clay deposits, which are often covered by considerable deposits of oolitic brown iron ore, contain irregularly stratified masses of cobaltic manganese ore, with 2·5 to 3·0 per cent. of cobalt and of chromic iron ore, a granular or so-called alluvial form, which latter mineral is also found in veins in the solid serpentine.

The nickel ore, which is newer in origin than those of manganese and cobalt, is found as a vein matter in hollows resulting from the shrinking of the red clay from the sides of the rock-funnel enclosing it. These veins vary very much in size, the maximum breadth being about 8 metres, but in some cases the whole of the rock is filled with small veins of mineral, so that it may be worked as a whole up to a thickness of 250 feet. Only the larger veins in the hard rock can be worked by systematic mining, as the walls are very irregular and may easily be lost in driving levels; by far the larger number of the workings are in open cast, at altitudes varying from 300 to 600 metres above the sea-level, where it is easy to follow the richer developments, and with a comparatively small preliminary outlay to make provision for some years of quarry working in the same locality. The preliminary working is mainly in the direction of removing the red clay, which can only be imperfectly separated from the ore by washing, and the iron ore it contains, if left behind, impoverishes the yield of nickel, besides being objectionable in the smelting, by reason of its adding alumina to the charge, which is sufficiently refractory from silica. These works are often a source of considerable expense, on account of the falls caused by the heavy spring and autumn rains and the difficulty of obtaining sufficient labour.

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[1] This is an extract from a long general memoir on the production and uses of nickel and its alloys. Only the portion relating to New Caledonia is given here, as the accounts of the Sudbury district and of nickel steel plates are mostly derived from English sources already available.

[2] Le Genie Civil.

As regards the latter point, apart from free white men who are mainly employed as artizans or sub-managers, at the Australian rate of wages of 12*s.* to 16*s.* per day, four different sources of labour are employed, namely, assigned convicts, those on restricted leave, natives and New Hebrideans of the Kanaka race, and Chinese, Annamites, and Tonkinese. The first two classes are very unsatisfactory, and the Kanakas, although of value for transport and lighterage service, are unfit for mining purposes, being unable to stand exposure to the mountain air, and, as a rule, the tribes object to working about their own homes, so that the work is principally done by immigrants from the New Hebrides; while the labour in the coffee plantations of the latter islands is largely furnished by New Caledonians. The Chinese are valuable workmen, but the supply from China proper, owing to political and diplomatic complications, has of late years been completely stopped, but latterly natives under contract have been brought from Tonquin, and the result appears to be satisfactory, their work, costing about 2*s.* 9*d.* per day, being better than that of convicts at nearly double the price.

The mineral is carefully sorted by hand at the quarries and divided into rich and poor qualities, the former containing 8 per cent. and above of nickel, and the latter all below that limit. As the hill-side workings are entirely without water, dressing operations can only be carried on in the lower ground. These are confined to simply washing away the red clay, and even this preparation cannot be carried too far without risking considerable loss (up to 3 or 4 per cent.) in the mud washed away. Hence the necessity of carefully clearing the waste away before working the mineral. The quarry waste, containing 3 to 4 per cent. of nickel, is not utilized.

The conveyance of the mineral from the mines to the coast is done principally by rope-ways, which are mostly of the simplest construction. When the produce is not more than 7 or 8 tons daily, the selected ore is placed in sacks holding from 100 lbs. to 120 lbs. attached to a hard wood-carrier, which is placed on the rope and allowed to slide down, for which purpose a slope of at least 18 degrees is necessary, the empty sacks being carried back by hand or mules, together with the carriers, which make fifteen or twenty journeys before they are worn out. The spans of the rope range from 500 metres to 600 metres, and in some instances 800 metres. From the lower stations the carriage to the shore is effected in carts, or by railway, but these distances are never very considerable, as only the mines within a zone of a few miles from the coast are actually worked.

The embarkation is done in lighters carrying 12 tons to 15 tons each, the cargoes being sent direct to Europe, or by trans-shipment at Noumea and Sydney. During the wool-shipping season steamers and sailing-vessels carry ore and regulus at nominal freights as ballast. The direct shipment in large sailing-vessels is less feasible, owing to the numerous accidents that have happened in navigating the reefs forming the coast, and the harbour of Noumea being the only one lighted, the other ports can only be approached in daylight, and with a fair wind.

The treatment of the mineral has undergone several modifications before arriving at the present practice. The original plan of Mr. Garnier was to treat it like iron ore by running it into pig-metal, which was afterwards to be refined in a reverberatory furnace to ferro-nickel. For this purpose two low blast-furnaces were built at Noumea, and a refinery with two Siemens furnaces at Septèmes, near Marseilles. Only the first part of the process gave satisfactory results, nickel-iron pig-metal having been obtained from the richer lumps, ores averaging 9 to 10 per cent. of nickel of the following composition: nickel, 65 to 68; iron, 29·5 to 23·0; sulphur, 1·5 to 2·5; silica and carbon, 3·5 to 5·0; and other matters, 1·5 to 2·5 per cent.; but it was found to be impossible to refine this in the reverberatory furnace, owing to the presence of sulphur, which has an extremely high affinity for nickel. It was therefore necessary to revert to the old method of concentrating the metal as sulphide by the addition of pyrites or sulphur. The average composition of the ore available for smelting was: silica, 45 to 50; iron, 16 to 14; nickel, 8 to 7; magnesia, 12 to 10; alumina, 3 to 5; water and oxygen, 16 to 14 per cent.

This requires from 25 per cent. to 30 per cent. of bases (oxide of iron or limestone), besides a sulphurizing material. As neither gypsum nor pyrites, free from arsenic and copper, was available for the latter purpose, the charge for the blast-furnace was made up as follows:—

	Kilogrammes.
Ore	1,000
Coral	300
Sulphur	35
Small coal or coke	75

The greater part of the sulphur passed into the regulus, and a fluid slag was obtained with 48·0 per cent. of silica, 12 to 13 of iron, and not more than 0·40 per cent. to 0·45 per cent. of nickel, but the local smelting was given up owing to difficulties in procuring coke, and now the ores are for the most part smelted in England, alkali waste being used as flux. The consumption of coke is about 20 per cent. of the weight of the charge, or about 30 per cent. of that of the ore treated. Small-sized water-jacket cupolas, smelting from 25 to 30 tons in twenty-four hours are used. The product contains nickel 50 to 55, iron 25 to 30, and sulphur 16 to 18 per cent., the latter being necessary to make the regulus sufficiently brittle to be easily powdered. The subsequent concentration may be done either in the reverberatory furnace or the Bessemer converter. In the former two calcinations, followed by fusion with quartz-sand, are necessary for the removal of the iron. The furnace treats 2 tons in twenty-fours, with the consumption of an equal weight of coal. The operation, which lasts eight hours, is controlled by sampling during the progress, and is stopped when the iron has completely disappeared, in order to prevent loss of nickel in the slags, which, however, are not thrown away, but are returned to the ore-furnace as they fine an excellent flux, besides containing 2½ per cent. of nickel. By the first concentration the iron is reduced to 2·5 to 3·0 per cent., and by the second to 0·5 to 0·75 per cent., the sulphur being kept to 16 per cent. at least. In the Bessemer converter the concentration is more rapidly done, a charge 1 ton of regulus melted in a cupola is introduced into the converter and blown with air at a pressure of about 40 centimetres of mercury. The temperature rises from the combustion of the sulphur, and sand is added to flux the iron. If the proportion of the latter metal does not exceed 36 per cent., it may be completely removed in about one hour and twenty minutes, but with a larger quantity the bath should be skimmed after blowing for twenty-five minutes and fresh flux added, as the fining will be imperfectly done if too large a quantity of slag is retained in the converter. When the slags begin to show signs of containing nickel oxide the refined metal is poured into moulds. It contains less than 0·50 per cent. of iron. Arsenic, antimony, and silver are removed either in the slags or by the blast; cobalt remains with the nickel sulphide.

The converter-slags are much richer than those of the reverberatory furnace, containing from 14 to 15 per cent. of nickel, mostly as shots of diffused regulus, which may in part be collected by running the slag into conical pots and separating the cake of metal at the bottom. The whole of it must in any case be returned to the ore furnace.

Attempts have beem made to continue the blowing up to the complete removal of the sulphur to produce a material that would only require a final reducing treatment to obtain pure nickel. This has, however, been found to be impossible, owing to the high affinity of nickel for sulphur, the heat developed in such an afterblow being less than sufficient to counteract the cooling effect of the air, and as the product when free from copper has a high melting-point, approximating to that of iron, it sets very rapidly, and blocks up the twyers.

The refined regulus, whether obtained from the reverberatory furnace or the converter, consists essentially of nickel sulphide (or nickel and copper sulphides, if obtained from pyritic ore like that of Canada), with not more than 0·50 per cent. of iron, and the same proportion of other foreign matters. It is crushed to pass a 65-mesh sieve, and charged in quantities of 600 kilograms upon the bed of a reverberatory calciner 10 metres long and 2·50 metres broad, with four working doors on one side, forming a layer about 2 inches thick, which is constantly rabbled and moved gradually from the flue of the fire-bridge end. The operation lasts eight hours with pure nickel sulphide, and only six when the regulus contains copper.

The consumption of coal is 2,000 kilograms for 2,400 kilograms of material roasted. The temperature is kept to dull redness, except towards the end, when the furnace is raised to bright red heat. The finished product, which should not contain more than 1 per cent. of sulphur, is ground to pass a sieve of 120 mesh, and subjected to dead roasting in a furnace of the same breadth as the preceding one, but with a shorter bed. The charge is 500 kilograms renewed every six hours, and the temperature is kept at bright redness; 3 tons of coal are burnt in twenty-four hours. The product is nickel oxide or nickel and copper oxides, and should not contain more than 0·40 per cent. of sulphur.

The reduction of the oxide is effected by mixing it to a paste with flour or other organic matters, dividing into small pieces when dried, and strongly heating with charcoal powder. Formerly the paste was cut into cubes of 12 to 15 millimetres, but in France discs of regular shape, 50 millimetres in diameter and about 15 millimetres thick, made in a press, are preferred. They must not be made thicker, or the reduction will be imperfect in the centre. The Chinese, who are somewhat considerable consumers of nickel, prefer to have it moulded into ingots similar to those used as money in China.

Formerly the reduction was effected in crucibles holding 50 to 60 kilograms in a gallery or reverberatory furnace, but, owing to the imperfect and irregular heating, the process was very wasteful of fuel, and the pots did not last for more than five or six operations. This method has therefore been abandoned in favour of furnaces working continuously. The first of these is a large muffle 3·5 metres long and 1·8 metre broad, heated by the flame of a gas-furnace, which is passed several times round it by a series of spiral flues. The shorter sides are closed by balanced doors, and the iron pots containing the mixture of oxide and charcoal are subjected to a gradually increasing heat for twenty-four hours, being entered at the coolest side and pushed gradually nearer to the fire-place. This, with mixed oxides, gives a coherent product; but pure nickel oxide, although it is reduced by carbon at a comparatively low temperature, must be subjected to a temperature of 1,100° or 1,200° for four hours to obtain the coherent metallic character required by the consumer; and, as such a heat is unattainable in the muffle, the operation must be finished in a crucible furnace.

Another and more improved plan of reduction is in a regenerative furnace resembling that used for reducing zinc oxide in Belgium, but having retorts open at each end. The mixture of oxide and charcoal is charged by a semicircular scoop at one end, and, when finished, the charge is pushed out at the other end into closed receivers, where it is allowed to cool out of contact with the air. A furnace with twenty-two retorts is capable of reducing 1,500 kilograms of nickel oxide, or 3,000 kilograms of nickel-copper oxides, in twenty-four hours, the charge of 750 or 800 kilograms requiring ten hours in the furnace in the first and five hours in the second case. About 2 tons of coal are required for heating in the twenty-four hours, and the work is done by two men per shift of twelve hours.

The reduced metal is sifted to separate the cubes or discs from irregular and broken masses, which are afterwards collected by a magnet. The former are polished by friction upon each other on a rapidly rotating barrel, while the latter is added in packing the barrels to make up the exact weight of 100 kilograms.

Among the more important recent applications of nickel is that of the alloy (20 of nickel, with 80 of copper) for the casing of bullets for the small-bore rifles adopted in modern armament. This combines a higher tenacity than that of the best brass with a high coefficient of elongation, the former being from 28 to 31 kilograms per square millimetre, and the latter 25 to 35 per cent., and exceptionally as much as 39 per cent., in the metal as cast. The coefficient of elongation increases with the freedom of the alloy from iron. By rolling cold, the tensile strength is increased to 60 or 62 kilograms, and the elongation is diminished to 3 or 4 per cent. When annealed under the most favourable conditions, the strength is 30 to 40 kilograms, and the elongation 32 to 39 per cent., as compared with copper, where the corresponding figures are 25·1 kilograms and 34·1 per cent.

The annealing of this alloy is a very delicate operation, requiring special manipulation, the details of which are mostly kept secret by the manufacturers. The principal object is to avoid oxidation, and this, according to the Author, may be most effectually done by separating the sheets in the annealing piles by sheets of card-board, which are carbonised during the process. If badly annealed, the mechanical properties are altered in a remarkable manner, the burnt metal having a tensile strength of 30 kilograms, with only 1 per cent. elongation. In a general way the annealing is considered to be bad if the tensile strength is below 33 kilograms, and the elongation less than 30 per cent.

The elastic limit is from 11 to 15 kilograms when well annealed, and 45 kilograms when the metal is hard from the rolls.

The ready malleability of this alloy seems to render it particularly suitable for locomotive fire-boxes, and plates for this purpose were exhibited by the Société des Métaux at the last Paris Exhibition.

The production of nickel, which was about 400 tons in 1878, the period of the discovery of the New Caledonia ores, rose to 1,200 tons in 1880, and 2,000 tons in 1884. The application of the metal to military purposes in 1886 created an extra demand of 400 to 500 tons per annum, and in 1887 the total consumption of the world was about 3,000 tons, of which amount New Caledonia supplied about 2,600 tons. Since that date the mines of the district of Sudbury have been largely developed, and at the present time copper-nickel regulus is equal to the daily output of 12 to 15 tons of pure nickel, or from 4,500 to 5,000 tons per annum. In New Caledonia arrangements are being made for an equal production, so that in the near future a total supply of from 9,000 to 10,000 tons of pure nickel per annum is likely to be available from these two sources.

In 1876 the price of refined nickel, which was then eighteen francs per kilogram, fell rapidly to ten francs and six francs, and ultimately, in 1886, to 5·50 francs to 5 francs, which rates have been nearly stationary ever since.

H. B.

The Production of Zinc in Upper Silesia in 1891.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1892, p. 271.)

During 1891 twenty-three different works were engaged in the treatment of zinc ores, one being specially devoted to the calcination of blende. These contained four hundred and ninety-six reducing furnaces, of which number one hundred and four with four thousand and sixty muffles were grate-fired, the remaining three hundred and ninety-two with fourteen thousand six hundred and four muffles being provided with gas-firing. The total consumption of muffles was 159,285.

The materials smelted and fuel and fire-clay consumed were:—

Calamine	297,260	tons[1];	83,420	tons	less	than in 1890.
Blende	186,698	,,	5,783	,,	more	,,
Zinc ashes and other intermediate products .	11,572	,,	1,815	,,	less	,,
Total ores . .	568,246		6,736	,,	,,	,,

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[1] Of 1,000 kilograms.

Fuel—

Coal and cinders . .	978,813 tons;	17,411 tons more than in 1890.
Fire-clay	30,726 ,,	7,420 ,, ,, ,,

Corresponding to a consumption of 6·44 tons of ore, 11·1 tons of fuel, 0·348 ton of fire-clay, and 1·8 muffle per ton of spelter produced.

The products were—

Crude spelter . . .	88,240 tons;	279 tons less than in 1890.
Cadmium.	2,849 kilograms;	1,309 kilograms less than in 1890.
Lead	772 tons;	114 tons less than in 1890.

The average value of spelter per ton was 443·09 marks in 1891, and 441·87 marks in 1890, and of cadmium 3·53 marks per kilogram (about 1*s.* 7¼*d.* per lb.).

In the rolling mills 38,922 tons of spelter were converted into sheet zinc, with a consumption of 41,788 tons of coal. The products were 37,699 tons of sheet zinc, 821 tons of lead from the refining furnaces, and 466 tons of zinc ashes. The average value per ton of sheet zinc was 450·47 marks (about 1*s.* 6*d.* per ton higher than in 1890).

The production of zinc-white was restricted to a single centre, where ten furnaces with ten muffles were in use. The products were 883 tons of zinc-white of various qualities, 23 tons of inferior grey and stone-coloured paints, 9 tons of lead, and 175 tons of residues returned to the zinc-smelting works.

The sulphur contained in the blende was partially utilized for the production of sulphuric and sulphurous acids. The plant for the former included thirty-six calciners and eighty-seven kilns, with ten vitriol-chambers of a total capacity of 40,600 cubic metres. The materials treated were:—

Blende	66,236 tons;	5,296 tons	more than	in 1890.
Nitre	77 ,,	14 ,,	less	,,
Nitric acid	189 ,,	79 ,,	more	,,

And the products were—

Calcined blende. . .	50,581 tons;	4,051 tons more than in 1890.
Sulphuric acid 50° . .	12,177 ,,	1,590 ,, ,, ,,
,, ,, 66° . .	7,902 ,,	1,254 ,, ,, ,,

In the two establishments engaged in the production of sulphuric acid, thirty-two calciners, or fifteen more than in 1890, heated 33,103 tons of blende, an increase of 6,638 tons on the preceding year, producing 1,589 tons of sulphurous acid.

The average value of sulphuric acid was 37·13 marks, and of sulphurous acid, 43·31 marks per ton. Six thousand four hundred and fifty-eight men and one thousand nine hundred and forty-four women were employed in the different branches of the zinc industry. H. B.

Aluminium.

(Dingler's Polytechnisches Journal, vol. cclxxxiv., 1892, p. 253.)

The great reduction in the cost of the manufacture of aluminium has rendered it possible to employ this metal for a number of purposes, which are detailed in this article. Amongst these may be mentioned the use of aluminium in the construction of sailing yachts, and three yachts, each of 10 tons displacement, but constructed respectively of wood, steel, and aluminium, are compared. It is shown that the steel gives a weight only slightly below wood, but that the use of aluminium reduces the weight to one-half, with the result that more ballast and larger sails may be carried. The stability of the three vessels are in the ratio of 1, 1·06, and 1·35 for wood, steel, and aluminium respectively; and by adapting the sail-surface to the stability in each case, the resulting speeds would be in the ratio of 1, 1·03, 1·16. Aluminium has also been used for the frames of railway-carriage windows, saving about 18 lbs. in the weight of each window. An alloy of 83 per cent. aluminium and 17 per cent. copper has been successfully used for steam-engine slide-valves, and an alloy containing 6 per cent. of copper is used for watch-cases. For telegraph purposes a wire is now made consisting of an aluminium core with copper coating, the conductivity of the compound wire being 69 per cent. of that of a solid copper wire of equal diameter. The admixture of 4½ lbs. to the ton of molten cast-iron produces specially sound castings, and directions are given how to mix and pour. The article contains other examples of the use of aluminium in the arts too numerous to mention in an abstract.

G. K.

On Electro-Plating Cast-Iron with Aluminium.

(The Iron Age, New York, 1892, pp. 337–1068.)

The new City Hall at Philadelphia, now nearly completed, has a tower intended to be 548 feet high, surmounted by a bronze statue of William Penn. This has been constructed up to 335 feet in white marble, the final 213 feet being made of cast iron, which is to be subjected to a dead plating in aluminium, to harmonize in colour with the masonry. The plating work has been undertaken by the Tacony Iron and Plating Company, of Tacony, Philadelphia, who have laid down the necessary plant and completed the covering of two of the large columns, 20 feet high, weighing 6 tons each, which are designed to carry the crowning dome of the tower.

The object intended to be covered with aluminium is carried by an overhead traveller into a shop containing six tanks arranged in two parallel series. These are made of wood, and are 28 feet long, 5 feet wide and 8 feet deep, or sufficiently large to take the largest casting in the structure. Each tank rests in a separate cement pit, the top of which is level with the floor. The pit is then filled with water, in order that both sides of the wood-work may be subjected to an equal fluid pressure. The object under treatment is deposited in the first tank, which contains caustic soda lye, and remains twenty-four hours, in order to remove grease. It is then transferred to the second tank, containing weak acid, where it is pickled to remove scale and oxide, remaining for another twenty-four hours. When taken out, the casting is thoroughly cleansed by hand with steel scratch-brushes, after which it receives a preliminary covering with copper by twenty-four hours' immersion in tank No. 3, a second and heavier coating of the same metal being given by seventy-two hours in tank No. 4. It is now ready to be covered with aluminium, which is done electrolytically in tank No. 5. The current is supplied by four large dynamos made by the Zucker and Levitt Company, of New York. The aluminium anodes used are each 4 feet long, 12 inches wide, and $\frac{3}{4}$ inch thick, and weigh 35 pounds, sixty of them being suspended round the interior of the tank. The thickness of the deposit is $\frac{1}{16}$ inch, corresponding to 50 pounds for each of the 20-foot columns. The operation requires seventy-two hours, the casting being turned every two hours night and day. The last tank contains hot water, in which the casting remains long enough to be thoroughly washed, and is then finished. The operation lasts nine days; but as the process is continuous, the finished objects succeed at intervals of three days. The total surface of the castings intended to be covered is about 100,000 square feet. The statue forming the finial of the tower is 38 feet high, and contains 50,000 lbs. of bronze, is built up in sections seventy-two in number, averaging about $\frac{1}{4}$ inch thick, which are flanged and bolted together.

H. B.

Pita-flax or Sisal-hemp.

(Annales Industrielles, Paris, July 24, 1892.)

The plant from which pita-flax is obtained is a native of South America and the West Indies, but it has been naturalized and become almost indigenous to all countries bordering on the Mediterranean—Algeria, Egypt, Sicily, Spain and Portugal—where it is much employed as a boundary hedge for roads and fields. It is a species of aloe with a fibrous root, a very short trunk, large fleshy leaves of a sea-green colour, with prickly edges and pointed ends, from 20 inches to 4 feet in length. The leaves increase in size year after year, and usually at the age of twenty or thirty years, but sometimes as early as its eighth year, a tall shaft is thrown up, which in about the space of a fortnight grows to the height of from 23 to 28 feet, and produces a flower at the top, but this so exhausts the plant that the effort usually kills it.

It is chiefly in the West Indies and Mexico that it is cultivated for profit. With the exception of the outermost and innermost leaves, of which the first are too coarse and the latter too tender, the rest are cut as near to the root as possible, and on being scraped and beaten with wooden instruments produce a valuable fibre of great strength. That from the exterior leaves is used for cordage and mats, from the intermediate leaves coarse cloths are made, and the inner leaves produce a fine quality of fibre from which delicate tissues are woven resembling fine linen. It is sometimes prepared in Spain of a sufficiently fine texture to be exported to Lyons for mixing with silk fabrics. The Mexican varieties of aloe, called in that country "Maguey," produce not alone a fibre which in France is known as Tampico horsehair, and in England as Mexican grass, pita-flax, or Sisal-hemp, but also a favourite intoxicating beverage (pulque), somewhat resembling perry, which is largely consumed in that country.

Hitherto the recovery of the fibre has in almost all countries been a tedious operation performed by hand, but in Yucatan a considerable trade has been created during the last few years by the application of machinery worked by means of horses or steam. From five thousand to seven thousand leaves are daily crushed and the fibre separated by means of a wheel fitted with metal blades which revolves in a circular pan, each thousand leaves yielding from 55 to 90 lbs. weight of dry flax, and in this way the Yucatan production has been raised to an average value of £200,000 per annum. This system, however, is in some ways objectionable, for it occasions a great deal of waste and often injures the attending workmen.

Mr. Berthet, who is already well known as the inventor of useful machinery of a similar kind, has recently introduced a greatly improved apparatus for the purpose which obviates those objections, and will no doubt supersede the older system. His machine is described and illustrated in vol. ix. p. 33, of the "Bulletin de la Société industrielle de Rouen," and consists of two parts. The leaves are first crushed between fluted rollers, and are then drawn continuously by means of an endless rope to a point where they are made to pass between a curved wooden support and a drum fitted with many blades. This drum in revolving tears away the pulp from the whole length of the leaves and lays bare the fibre, but the operation is again repeated by the position of the leaves being automatically reversed and drawing them through a second drum which completes the separation of the fibre.

In his work on the "Fibrous plants of India," Mr. Forbes Royle gives the result of many tests made by him in India of the comparative strength of pita-flax and other fibres. He found it to be 70 per cent. stronger than Russian flax, and also that it has greater resistance than cocoanut fibre; when wet it shrinks 25 per cent.

less than ordinary hemp-rope. The British Consul at Aden has also recently reported at some length on the mode of preparation of the fibre in the Somal country.[1]

O. C. D. R.

Improvements in Switching-Arrangements for Secondary Batteries. By J. TRUMPY.

(Elektrotechnische Zeitschrift, 1892, p. 262. 1 Fig.)

The Author alludes to the great cost and expensive maintenance of the switching-arrangements which are at present used in Germany for secondary batteries. If either the three- or five-wire system be used, this necessitates a great number of wires in the accumulator room, which often hinders the work. As it is advisable to have the battery always in connection with the outer net-work, switching apparatus must be provided, so that a constant potential may be kept up.

The Author states that it is usual to provide a third part of the cells of a battery with switching-apparatus, but that by the system he describes it is only necessary to fit up in this way one-sixth of the cells.

The dynamo may also be built to give a lower potential, as one-sixth of the cells can be cut out during the charging.

A diagram of connections is given, which shows a dynamo, connected by one of its terminals to the end cell of the battery; the other pole of the machine is connected to a switch, which makes contact with any one of the last five cells. The sixth cell from the end is connected to a switch, which may be on either of two contacts, one of which is connected to the fifth cell from the end, and the other to the dynamo. The net-work is connected to one end of the battery, and to a switch which makes connection with any one of the last five cells of the battery. At the beginning of the charge both of the five-way switches are in connection with the end cell, and the two-way switch is so placed that cells number five and six are connected directly in series. The dynamo is thus charging the whole battery in series, and the net-work is also being fed by the whole of the cells. As the electromotive force of the cells rises in charging, the five-way switch on the discharge side is gradually moved back until all the five regulating cells are switched out. As soon as this has been done, as the electromotive force will still be rising, it is necessary to make the following changes. The five-way switch on the charging side is also put on to the fifth cell from the end, and the two-way switch placed so that the dynamo is charging the whole battery in series, except the regulating cells. The five-way charging switch is now moved until, for example, it stands on the second cell from the end; the dynamo is then feeding the outside circuit, but the electromotive force is reduced by the fact that one, two, or more cells, are in the supply circuit, and so reduce the electromotive force at the lamps. When the charging of the battery is nearly complete the dynamo is therefore connected to the end cell, and also to the sixth cell, and the outside circuit switch is connected to the fifth cell. If the machine be stopped, the five-way charging switch is gradually moved from contact one to two and so on, and as soon as it reaches the fifth cell, then the two-way switch is changed over, and the dynamo is again only connected to the five-way switch, and the whole of the cells are in series. The Author states that this plan has been found very simple and successful, and has been in use for some time at the accumulator works at Hagen in Westphalia. He also recommends that a small dynamo should be at hand suitable for charging one or more of the regulating cells if necessary.

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[1] "Colonial Reports—Annual—No. 44: Bahamas," paragraph 15, deals with Fibre Cultivation, and shows how important the subject is there considered.—SEC. INST. C.E.

E. R. D.

New Type of Accumulator for Traction-Work.

By Weyde-Clas-Elsner.

(Elektrotechnische Zeitschrift, 1892, p. 263. 1 Fig.)

The Author describes the various properties which a good type of cell ought to possess, and remarks that such cells are subjected to very rough usage in traction-work. They should be able to discharge very large currents, and should be as light as possible. The new cells differ in many respects from those most in use in this country. Long thin channels of celluloid are used as supporting frames. The cross section of the channels is approximately one-third of a circle. The active material consists of peroxide of lead, and it is pressed into solid short cylinders as hard as the carbon for arc-lamps; each cylinder has a hole along its axis, and they are all "formed" before being placed in position. They are then coated with a special conducting cement, and laid at a short distance apart inside two channel-shaped strips of sheet lead, each of which is provided with a wide lug at one end. Each set of five cylinders, with the lead conducting strips, are then placed inside a pair of celluloid channels. About eight of these complete sets are then mounted vertically, and held together by bands of celluloid. Celluloid tubes also pass through holes at each end of the celluloid channels. The whole is held firmly together by wooden wedges. All the lead strips are then soldered on to one common bar, and the compounds form either the positive or negative plate in a cell. It is claimed that the construction is solid, and that only the thin lead conductors on the positive plates deteriorate, and can easily be renewed. E. R. D.

The Fleming Standard Cell. By Dr. Lindeck.

(Elektrotechnische Zeitschrift, 1892, p. 161.)

The Fleming-cell consists of amalgamated zinc in sulphate of zinc solution and a copper cylinder coated electrolytically with a layer of pure copper in a solution of sulphate of copper. The electromotive force of the cell when the density of both solutions is 1·200 and the temperature 15° Centigrade is given by Fleming as 1·104 legal volt. With a copper solution of 1·100 and a fine solution of 1·400 density, the electromotive force at 15° Centigrade is 1·074 legal volt. The Author has tested the Fleming standard cell in the Government Laboratory at Berlin, and in publishing the results of his tests compares them with those given by Fleming, Lord Rayleigh, Weber, and Voller. The tests were made by using a Clark standard cell, the latter being frequently calibrated by means of a silver voltameter.

Density of Solution.		Electromotive Force in Legal Volts.	Observer.
ZnSO$_4$.	CuSO$_4$.		
1·200	1·200	1·104	Fleming.
1·200	1·200	1·104	Rayleigh.
1·200	1·200	1·106	Lindeck.
1·200	1·100	1·075	Voller.
1·200	1·100	1·10	Weber.
1·200	1·100	1·101	Lindeck.
1·400	1·100	1·074 to 1·083	Fleming.
1·400	1·100	1·087	Lindeck.

G. K.

An Automatic Regulator for the Consumption of Electricity.

By F. Miron.

(L'Industrie Electrique, 1892, p. 126. 4 Figs.)

The Author states that in France the system of sale of electricity by meter has not found favour in all cases; and that there are circumstances in which the supply company undertakes to supply the light by contract for the whole number of lamps used, or for a certain less number than the maximum installed. In the latter case, it is obvious that unless some means be taken to check the consumer, he will be able to defraud the company by using a greater number of lamps than he has stipulated for. Two methods have been employed, with the object of preventing such frauds; the one consisted in placing a fusible cut-out in the customer's main, calculated to fuse when the current in use exceeded that agreed upon; the other consisted in so grouping the lamps on the premises of the customer that he could only switch on a given number at one time. Both these methods were found very unsatisfactory; the former, because any slight variation in the potential on the supply-mains might cause the fuse to melt, and also the possibility of burning a few more lamps than the number stipulated, as the fuses could not be put in so as to be absolutely accurate; the result was that larger fuses had to be employed, and therefore more or less loss accrued to the supply company. The latter method, that of grouping the lamps, was found unsatisfactory, because a customer was not at liberty to use which lamps he pleased; and on the other hand, the switches adopted could be readily tampered with, and a piece of wire properly fixed would enable the customer to burn many more lamps than were agreed upon. A special controlling apparatus was therefore invented by Mr. Maxime Laille, which appears to give satisfactory results in practice. It is so designed that when the stated number of lamps is exceeded, the whole current is either switched off altogether, or all the lamps only burn at a dull red. When the extra lamps are cut out of the circuit, the apparatus automatically allows the full current again to flow.

The apparatus is formed as follows. An electromagnet, an oscillating armature, and two mercury contacts, form the principal parts. The core of the magnet consists of a bar of soft iron, bent into the form of a closed rectangle. About half the length of the longest side is then cut out, and forms the armature, which swings freely upon a pivot above its own centre of gravity. A tumbler is so arranged that as soon as the armature tilts to one side, it is immediately carried down until one or other contact attached to each end falls into a mercury cup. The current may be supposed to enter the house at +; it flows to the right hand mercury cup, through the armature, round the electromagnet, and so to the lamps, which are fed in the usual way, and the current leaves at −.

In case, however, the number of lamps which should be lighted is exceeded, the current flowing round the electromagnet increases sufficiently to cause the armature to tilt and make connection with the left mercury cup. The current from + now flows, first through a resistance, then round the magnet, through the armature, left cup, again round the magnet, and so to the − pole; the whole of this circuit is a shunt. Some current will, in most cases, still flow to the lamps, but will only keep them at a dull red. If now some of the lamps be switched off, the position of the armature will be reversed, and the normal conditions will be resumed.

The Author states that upon a circuit of 110 volts, with a stipulated number of sixty lamps to be used as a maximum, the apparatus will switch off the current when two extra lamps have been lighted, making, in all, sixty-two. He states that the smallest size made is for two lamps of 10 candle-power, and the largest for sixty lamps of 10 candle-power.

E. R. D.

The Patin Alternator.

(L'Industrie Electrique, 1892, p. 226. 3 Figs.)

This alternate current dynamo for high tension is somewhat similar in appearance to that proposed by Mr. Anatole Gerard ten years ago; but in reality it is very different in many respects.

In this machine the field magnets rotate and act as the fly-wheel of the steam-engine, or are fixed direct upon the shaft of the turbine used for supplying power. The armature is stationary. This arrangement obviates the use of ropes or belts for driving, and is stated to reduce the space occupied by the combined plant.

The speed required for ordinary dynamos has rendered necessary the use of high-speed engines; but the dynamo has been designed so that it can be coupled direct to Corliss engines running at low speed and with high economy.

The frame of the field magnets is formed as a fly-wheel, and is keyed directly upon the main shaft. It consists of two rings of cast-iron, into each of which are cast a series of soft wrought-iron field-magnet cores. The inner ring is cast solid, with the spokes of the wheel, while the outer is cast separate, and is fixed to the wheels by arms. The stationary armature can be moved laterally by means of a hand-wheel controlling a screw, which is connected by rods to the armature framework. The armature coils consist of copper strip, wound upon cast copper cores of a bent form to suit the radius of the wheel. These copper cores are held in position by gun-metal straps fixed into the armature disk by means of a special cement.

The figures in the original represent two alternators, one for 40 kilowatts and the other for 75 kilowatts. The principal data of the latter are—

Number of field-magnets	76.
Electromotive force	2,400 volts.
Current	31 amperes.
Speed of the periphery	48 feet per second
Resistance of the armature	0·75 ohm.
Length of armature wire	1,700 feet.
Section ,, ,, ,,	0·0046 square inch
Energy spent in excitation	2,500 watts.
,, ,, ,, armature	720 ,,
Electrical efficiency	96 per cent.

E. R. D.

An Instrument for Calibrating Torsion-Galvanometers.

By Dr. Köpsel.

(Elektrotechnische Zeitschrift, 1892, p. 323. 1 Fig.)

This is a new instrument brought out by the Author, who is in the firm of Siemens and Halske, of Berlin. It enables a torsion-galvanometer to be calibrated by means of a Clark standard cell, and affords means of checking the electromotive force of the standard cell at the same time.

In the main circuit are placed in series an accumulator, an adjustable resistance not necessarily of known amount, a resistance-box of seventeen coils, each of 143·3 ohms resistance, of which one or more can be put in the circuit by means of plugs; a silver voltameter provided with a plug for short-circuiting it, and the torsion galvanometer to be calibrated. A second shunt circuit is joined to the ends of the resistance-box, and this circuit contains a key, a reflecting galvanometer, a carbon resistance of about 100,000 ohms, and a Clark standard cell. The method of testing is as follows:—The silver voltameter is cut out of the circuit. It is obvious that, by adjustment of the resistance coil near the accumulator, a potential of exactly 1·433 volt can be obtained between the terminals of the seventeen coil resistance box. The Clark cell gives also 1·433 volt, and as it is coupled in the reverse way to the accumulator, when a balance is obtained, the mirror galvanometer will remain at zero, while the test-key is pressed down. Supposing this to be the case, if one of the coils in the box is plugged there will be a current of 0·01 ampere through the torsion-galvanometer, which should give a deflection of 10° if it is correct, if not, the deviation is noted. Two coils are now plugged, and a current of 0·02 ampere will pass, giving a deflection of 20°, and the tests are then carried on until the whole of the coils are plugged in parallel, giving a current of 0·17 ampere, and a deflection of 170° if correct. In order to make sure that the Clark cell is giving the exact potential of 1·433 volt the silver voltameter is now put in circuit, a current of 0·17 ampere is used, compensation again obtained as before; the galvanometer is then switched out and an equivalent resistance switched in, and the current allowed to flow through the voltameter for a given time. If the Clark cell is in good order, no variation will be found in tests carried on over a period of six months.

E. R. D.

A Recording Wattmeter for 500,000 *Watts.* By G. Roux.

(L'Industrie Electrique, 1892, p. 179. 1 Fig.)

Messrs. Richard Brothers, of Paris, have just completed four recording wattmeters for the Compagnie Continentale Edison, for 5,000 amperes, and 110 volts. The fixed circuit consists of eight U-shaped copper plates, coupled, in parallel, by means of six large bolts, and having a total section of 7·7 square inches. The bars are separated from each other by small copper distance-pieces, to allow free circulation of the air, and promote cooling. At the centre of the magnetic field, which is practically uniform between the limbs of the copper bars, is placed a spherical bobbin, wound with fine wire, and keyed upon a horizontal spindle, which is pointed at one end, and formed into a knife-edge at the other, where it rests upon a hardened steel plate.

One of the ends of the wires on the bobbin is connected to the fixed circuit, and the other to an additional resistance.

The horizontal spindle carries a counterbalance, and also a long aluminium pointer, at the end of which is a reservoir pen of the usual type, acting upon a cylinder, which makes one revolution in twenty-four hours. Attached to the spindle is a small lever connected to a glycerine dash-pot.

The Author states that two of these instruments are in use at the Trudaine station of the Compagnie Continentale Edison, and also two at the Drouot station. He believes that these are the largest recording watt-meters ever made.

E. R. D.

The Capacity of Telegraph Insulators. By — Lagarde.

(Annales Télégraphiques, 1892, p. 125. 8 Figs.)

The Author refers to accounts of previous tests upon the insulation of telegraph insulators, which he published in the "Annales Télégraphiques," in January, 1888. At that time he did not ascertain the capacities of such insulators; but as this is an important factor in telephony, Mr. Jaulin made the following tests, under the direction of the Author. The method used was that of Sauty, in which a Wheatstone bridge is employed; and the usual standard resistance and the resistance to be measured are respectively replaced by a standard condenser C, and the condenser to be tested C^1. When the galvanometer remains at zero, whether the key be opened or closed, then the formula $C^1 = C\frac{R}{R^1}$ holds good, where R and R^1 are the respective resistances of the arms of the bridge. In these tests, the standard condenser C was of 1 microfarad capacity divided into tenths, and C^1 was replaced by four insulators of the particular pattern under examination. R and R^1 were resistances which could be varied from 1 ohm to 1 megohm; and the battery consisted of either four, ten, or one hundred cells of the Marié-Davy type.

Illustrations are given of the various classes of insulators which were tested. The first examined were of the double-bell type, made in one piece of porcelain. The four insulators were attached, by their ordinary metal supports, to a wooden cross-bar; and the supports were connected together by a wire 0·039 inch diameter, while another wire, 0·156 inch diameter, was carried round the neck of the four insulators in series. These two wires formed the plates of the condenser. On experiment, it was found that the capacity of the four together was $C^1 = 0 \cdot 00028$ microfarad; so that the value for each was one-fourth of this, or 0·000070.

The wire was next removed from the necks of the insulators; and they were inverted, and hung so that the necks were in water.

The two plates of the condenser were then the water, and the wire joining the stems together. The results were—

1. $C^1 = 0 \cdot 00030$; or, for one only, $Ci = 0 \cdot 000075$.

As this value was practically the same as that previously obtained, and the second method of testing being somewhat simpler, it was adopted afterwards for all the other tests.

2. Insulators, with a single bell, gave—

$$C^1 = 0 \cdot 00047 ;\ Ci = 0 \cdot 00011.$$

3. Telephone insulators, with double bell,

$$C^1 = 0 \cdot 00060 ;\ Ci = 0 \cdot 00015.$$

4. Telephone insulators, with single bell,

$$C^1 = 0 \cdot 00095 ;\ Ci = 0 \cdot 00023.$$

5. Insulators, with two bells made separately, and cemented afterwards,

$$C^1 = 0 \cdot 00037 ;\ Ci = 0 \cdot 00009.$$

The thickness of the porcelain at the neck of the various types was as follows:—

		Inch.
Type 1.	Thickness	0·48
„ 2.	„	0·43
„ 3.	„	0·39
„ 4.	„	0·32
„ 5.	„	0·35

It is thus obvious that the capacity of the insulators increases as the thickness of the neck decreases, with the single exception of the type 5, which is constructed differently.

All the insulators were dried before the tests were made; and their respective insulation resistances were as follows:—

		Megohms.
Type 1.	Resistance	500,000
„ 2.	„	500,000
„ 3.	„	248,000
„ 4.	„	164,000
„ 5.	„	124,000

In ordinary use the insulation is much inferior.

E. R. D.

The Electrostatic Capacity of Telegraph Lines.

By E. BRYLINSKI.

(Annales Télégraphiques, 1892, p. 97. 3 Figs.)

The Author refers to an article by Mr. Vaschy, published in the "Annales Télégraphiques," November–December, 1891, in which reference was made to the fact that the theoretical capacity of an aerial line is always very much lower than that obtained in practice; and he attempted to explain the difference by the action of neighbouring wires. He alluded also to the condenser effect of the insulators; and the Author was led to make tests upon this subject. In the case of a single line, after rain the insulator is covered with moisture; and this is also the case with the metal support and the post. As the porcelain is dry inside, it is a true condenser. A covering of dust upon the insulator has the same effect as water, but in a less degree.

In the case of a telegraph line, there is first the capacity of the wire, and to this must be added that of the insulators.

The Author tested a single-bell insulator by means of three hundred Callaud cells, of large size, in August, 1889, and found its capacity to be $2 \cdot 12 \times 10^{-10}$ farads, or 0·000212 microfarad.

Taking a line, having 24 posts to the mile, with wires of 0·156 inch diameter, at a height of 5 or 6 yards from the ground, the capacity per mile, reckoning 0·0002 microfarads per insulator, would be as follows—

	Microfarad.
Theoretical capacity of the wire	0·0107
Capacity of the insulators	0·0048
	0·0155

The Author then quotes figures obtained by Mr. Massin, which prove that the capacity of a line increases with the humidity of the atmosphere. He then describes the method he himself employed to test the capacity of the insulators. A discharge key, with two contacts, was arranged in circuit, so that when it touched one contact piece, a condenser and galvanometer were in circuit, and when it was upon the other contact, both these instruments and a battery were in circuit. The Author then explains the advantages which he considers this method to have over others. He used a Thomson astatic galvanometer, by Elliott Brothers, having about 8,000 ohms resistance, and giving a deflection of one hundred and twenty-three divisions upon the scale for a continuous current equal to a tenth of a microampere. The battery consisted of one hundred and twenty-one Minotto cells in series. Their resistance was negligable in comparison with that of the insulators or standard condenser.

The standard condenser was one microfarad capacity, divisible by thousandths. For the tests, the Author took five double-bell insulators, and attached a wire to the metal supports, and another was passed round the necks of all the five insulators. The insulators were thus charged in parallel. The first test was made with dry insulators; the second, after they had been wiped with a wet cloth. The Author then gives the results of his tests in tabular form; experiments were made with one insulator alone and afterwards with two, three, four, and five, in a group. He draws up a long series of equations, from which he deduces formulas. The general result of the whole work is, however, that he finds the capacity per insulator, when dry, to be $1 \cdot 2 \times 10^{-10}$ farads, or 0·00012 microfarad; and when wiped with a wet cloth, the capacity becomes $4 \cdot 3 \times 10^{-10}$ farad, or 0·00043 microfarad, showing the great difference caused by a shower of rain. When allowance is made for the capacity of the insulators as well as of the wire itself, theoretical values closely approximate, for any given line, to the values obtained in practice.

E. R. D.

The Prevention of Cross Contacts in Telephone Lines.

By W. Christiani.

(Elektrotechnische Zeitschrift, 1892, p. 272. 2 Figs.)

The Author states that the equipment of lines, consisting of numerous telephone wires with double insulators placed only a short distance apart, has, with a certain show of reason, been objected to. It was supposed that when such wires were carried from post to post, that cross contacts would be caused by the swinging of the wires in the wind. He remarks that, even should this be the case, it would not give rise to much annoyance, as it would not cause a stoppage, and it would be simple to make an earth connection on each side, and use the two wires in parallel until the fault was rectified, in this way making the double wire for the time being into a single line with earth return. It is only when several spans become entangled that much difficulty is caused, and then only from the induction effects, as each pair can still be used as a single line.

In the case of lines in which the wires are crossed diagonally at stated intervals, there is a much greater probability that a wire of one circuit will foul a wire of another circuit, and cause an entire stoppage of work in both. The Author's proposal is to attach the two wires of a double telephone line to two insulators placed at a distance of 6·46 inches apart, and in such a position that a line passing through the two wires would make an angle of 45° with the horizontal. This method he considers at least as favourable as the plan used by the Government, in which the two wires are in the same horizontal plane at the points of support, and are at a distance of 6·85 inches apart. The Author then describes the methods of preventing the loops of wires from fouling, but is of opinion that in many cases such aids are unnecessary. He gives an example, in which it appears that much trouble was caused by flocks of geese flying against the wires, and also by high winds.

In such cases he recommends the use of a double insulator, or rather of two insulators attached together by a short bar, and made of such a shape that the bell of the upper one covers and protects that of the lower. The combined insulator is to be placed at the lowest point of the span, and one of the wires is to be attached to each bell. The wire may be either directly attached to the porcelain, or may be passed through a tube of some non-conducting material which is fixed to the bell. With this arrangement, if the two wires be purposely twisted together, they will immediately untwist themselves when freed. In this way the two wires swing together. Another method which the Author recommends for a number of pairs of wires, which are placed in pairs according to his plan, is to provide an iron bar, with cross-pieces at suitable heights; each cross-bar carries a pair of insulators at the regulation distance apart, and at the proper angle with each other. The entire arrangement is intended to be made as light as possible, and to be attached to all the wires at the middle of each span. In case the weight of the fitting should be thought too great, where a large number of wires are to be supported, the top of the bar may be formed into a hook, and the weight carried by a special wire, in the way telephone cables are often carried across streets.

E. R. D.

A Comparison of the Vacuums in different Glow-Lamps.

By C. Boccali.

(Elektrotechnische Zeitschrift, 1892, p. 249. 2 Figs.)

The Author is assistant engineer at the testing station at Munich, and the experiments which he quotes were made upon lamps of exactly the same kind, and manufactured by the same firm. He remarks that a conductor through which a current is passing becomes heated, and attains a temperature which depends not only upon its own dimensions, but also upon the surroundings. Since the resistance alters with the temperature, the same conductor, through which the same current is passing, will show a different resistance with different surroundings. Two curves are shown which were obtained from a glow-lamp of 65 volts and 16 candle-power, placed in a bath of petroleum which was kept at a constant temperature of 68° Fahrenheit. One curve shows the relation between resistance and current while there was a vacuum in the lamp, from which it appears that, with the smallest current measurable, 0·1 milliampere, the resistance was 183 ohms, and it gradually decreased until with 50 milliamperes it was only 137 ohms. A small hole was then made in the glass, and air let in. A similar curve was then obtained, and showed that with a current of 50 milliamperes, the resistance had only fallen to 174 ohms. The Author makes use of this great sensitiveness in the value of the resistance to compare the vacua in different lamps. When otherwise similar lamps have different vacua, currents of different strength are required to bring the filaments to the same temperature, for the quantity of heat is greater or less according as the vacuum is more or less perfect. The Author then describes his method of making the necessary tests. A petroleum bath is kept at a temperature of 68° Fahrenheit, and the current is noted which is required to raise the temperature of the filament to 122° Fahrenheit. For this purpose an arrangement of Wheatstone bridge and galvanometer is used, which is described in detail. The bath is first heated to 122° Fahrenheit, and the resistance, R, of the filament is taken; this must be obtained with a current of about 0·3 milliampere, so as not to heat the bath. The bath is then cooled to 68°, and the resistance of the filament remaining the same, the current C is noted. This value C represents the current which is required to heat the filament to 122° Fahrenheit, while the surrounding temperature is 68°. The resistance *r* is that of the filament at 68°, and is obtained with a current of 0·3 milliampere. The Table on next page gives the results of experiments made upon seven lamps of 65–66 volts and 16 candle-power of the same type and by the same makers.

It appears, therefore, from these tests, that No. 1 lamp is very much the best, as it required only 7·85 milliwatts to heat it to 122°, while No. 7 required about double. The difference in resistance of the filaments is not 9 per cent., and is not enough to account for the figures R × C. The results are therefore caused by differences in the vacuums of the lamps. A check test was made by a different method. In order to obtain equality of temperature inside and outside the lamp, a certain time is necessary, and the better the vacuum the longer the time needed. The exact time is difficult to measure, but for a series of lamps figures can be obtained which depend upon the time.

Lamp. No.	Ohms. r.	Ohms. R.	Milliamps. C.	Milliwatt. R × C.	a.
1	182·9	178·0	6·64	7·85	186
2	169·8	164·8	7·24	8·64	183
3	188·6	183·5	7·14	9·52	176·5
4	161·7	157·4	7·81	9·60	182·5
5	159·4	155·6	9·00	12·60	180·0
6	165·8	161·2	9·20	13·61	173·0
7	172·0	167·4	9·40	14·80	168·5

In place of the lamp, a resistance equal to its resistance at 122° is inserted, a current C is passed through, and the throw of the galvanometer made equal to, say, two hundred scale divisions. The lamp is now inserted, and the throw observed; this will always be less than 200, and will vary according to the perfection of the vacuum. In this way the figures in column a were obtained; these all agree with the other results, except that for lamp No. 3, and the discrepancy in this case is due to the fact that the filament was much out of the centre, and near to the glass globe at one point.

E. R. D.

The Use of Arc-Lights Indoors. By K. Friedrich.

(Elektrotechnische Zietschrift, 1892, p. 148. 4 Cuts.)

In this article the Author describes certain improvements in the dispositions and screening of arc-lamps due to Mr. Hrabowski, and which have been successfully applied in an evening school for artisans in Berlin. The arrangements finally adopted were the outcome of experiments extending over five years. The lamps, as originally arranged, were placed within large cone-shaped reflectors, throwing the light upwards against the white ceiling, whilst at the same time preventing the lamps from being seen. It was found that the ceiling and the upper parts of the walls received too much light, whilst on the tables and drawing-boards there was not enough. In the latest arrangement no use at all is made of the reflecting power of the ceiling, but each lamp is provided with thin semi-transparent reflectors. Two of these are truncated cones with vertical axes, and rest in a circular plate placed horizontally close under the lamp, the reflectors being so placed that no direct rays can pass out. The light which reaches the floor and tables is either reflected, or has been diffused by passing through the semi-transparent reflectors. For the illumination of special objects a large white and opaque screen is used with two 9-ampere lamps placed in front; the direct rays of the lamps are diffused by two small semi-transparent screens placed in front of them. The article is illustrated by reproductions of photographs of objects of art taken with daylight, with naked arc-light, and with the improved arrangements of arc-light described.

G. K.

Practical Notes on the Electrolytic Refining of Copper.

By F. B. Badt.

(The Electrical Engineer, New York, vol. xiii., 1892, p. 598.)

This Paper contains a tabulated list of the various refineries electrolytically worked in the United States, with a statement, not guaranteed as absolutely correct, of the electrical details of current and vats and monthly outputs at each; the sum total of the latter reaching 3,650 tons, the capital invested in the several undertakings being over £200,000.

The most general arrangement of vats is the ordinary multiple system of connection of plates as in secondary cells, the anodes and kathodes being all in parallel ineach vat, and the vats being connected in series and parallel to meet the electrical requirements; one advantage of this system in the absence of royalty payments to the patentees of other systems, such as Smith's, where the anode and kathode are disposed horizontally, with other unconnected plates interpolated, and a strainer of cotton cloth introduced between for intercepting impurities falling from the plate above, or Hayden's, where similar plates are interpolated, but horizontally disposed, and the use of strainers is discarded; or Stalman's, which is practically the same as the last described method, but the interpolated plates are formed of one refined and one unrefined plate riveted together without liquid between.

The crude material is in general black copper cast into plates of convenient size, and containing 97 per cent. to 98 per cent. of pure copper, and in most of the works in the raw material introduced, though in some the plates are smelted and run from matte of 45 per cent. to 54 per cent. copper.

The solution employed is sulphate of copper, and this is in all cases purchased and not manufactured on the spot.

It should be noted that matte containing less than 30 ozs. of copper per ton sells at the market price of copper matte; but if the silver is over that amount, then it is also paid for according to the assay results.

One pound of copper per hour is deposited by about 386 amperes; but the efficiency of the plant can be theoretically raised to any figure by increasing the number of vats and the size of plates, though in practice certain limits are reached which cannot be economically surpassed.

The usual density of current adopted is about 10 amperes per square foot, and this cannot be exceeded without affecting the purity of the copper deposited.

Good circulation of the liquid is also indispensable, and different methods for obtaining it are described; the most successful being afforded by two collecting-tanks, into either of which the liquid flows after circulating through the depositing vats, fed from a storage-tank at higher level; these collecting-tanks are used alternately, and when one is full it can be closed, and the liquid forced up to the storage-tank by air-pressure.

The scheme advocated for the dynamos is that of separate excitation of the field-magnets so as to avoid reversal of current and fluctuation of the voltage.

The cost of a plant to deal with 1,000,000 lbs. of refined copper per month, and driven by water-power, is put at about £25,000, to which must be added the cost of copper under treatment, say £16,000, and if steam power be required, an additional cost of £4,000 must be allowed. Electrolytic refining is, therefore, expensive as regards the cost of plant, and should, therefore, be erected on carefully prepared plans of both electrical and mechanical details.

F. J.

The Specific Resistance of Peroxide of Lead.

By J. F. Weyde.

(Elektrotechnische Zeitschrift, 1892, p. 315. 1 Fig.)

The subject discussed in this article had been previously alluded to on p. 199 of the same journal; and the Author states that the results of experiments made by Dr. Shield tended to show that the specific resistance of peroxide of lead (H_2PbO_5), *sic*, formed by electrolysis, reached 6·78 megohms per cubic centimetre; and that of the same salt, produced by chemical means, was 5·59 megohms per cubic centimetre.

The Author has made numerous experiments on the subject of the specific resistance of rod of peroxide of lead, and has always found the value very much lower. His tests were made upon cylindrical rods of pure peroxide of lead, from accumulators which had been three years in actual use, and were therefore entirely formed by electrolysis. Crystalline layers could be seen on the broken section by means of the microscope. The type of cell has been described in a former abstract; and the active material is in the form of cylindrical rods, like lamp carbons, with a small hole up the centre. The rods were first carefully washed free of acid, and then dried for six weeks in air, and lastly, by heating them upon a steam boiler. The ends were then cleaned up, and the extremities of the central channel stopped with wax. An india-rubber elbow was then fixed to each end and filled with mercury, into which the ends of the circuit wires dipped. The Author attaches much importance to the quicksilver contact, as he states that, with a dry contact, a very great resistance is produced. He found that cylinders, such as he used, were comparatively good conductors; and that when they were from 1·17 to 1·95 inches long, and inserted in a circuit of 100 to 120 volts pressure, that small sparks were produced on breaking contact with the peroxide, and that a cylinder, 5·85 inches long, and 0·507 inch diameter, could be placed in series with glow-lamps of 60 volts, requiring about six amperes, without diminishing them to half their candle-power. The resistance of the cylinders, however, rises gradually, and the light of the lamps diminish, until the wax-plugs melt, and the mercury fills the interior of the cylinder. The following measurements were made with a Siemens universal galvanometer, and a cylinder 4·953 inches long, 0·507 inch diameter, with a hole 0·1365 inch up the centre. The first measurement gave 4·45 megohms, after which the readings were 5·45, 9·00, 11·50, 14·00, 17·80.

This gave a minimum specific resistance per cubic centimetre of 0·4308 megohms, as compared with the values 5·6 to 6·8 obtained by Dr. Shield.

The Author then used smaller currents, and found that the resistance rose more slowly; he therefore considered that polarization took place between the mercury and the peroxide of lead, and found that the value of the observed resistance immediately fell when the piece under test was shaken. A similar test-piece to that last described, but 2·886 inches long, gave, after a short time, 9·53 megohms, and afterwards 14·79 megohms; but directly after vigorous shaking, the reading was only 1·43 megohm. This figure was obtained repeatedly; and the specific resistance was therefore only 0·237 megohms per cubic centimetre. With various other test-pieces, the Author obtained the values for specific resistance 0·14, 0·17, 0·188, 0·19, 0·21, 0·38, 0·42, and 0·45 megohm, as the maximum.

He therefore believes that errors have occurred in Dr. Shield's experiments; and commends the subject to the attention of other electricians.

E. R. D.

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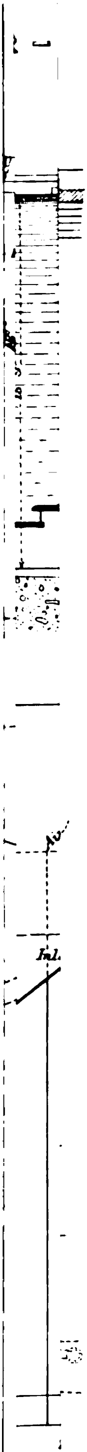

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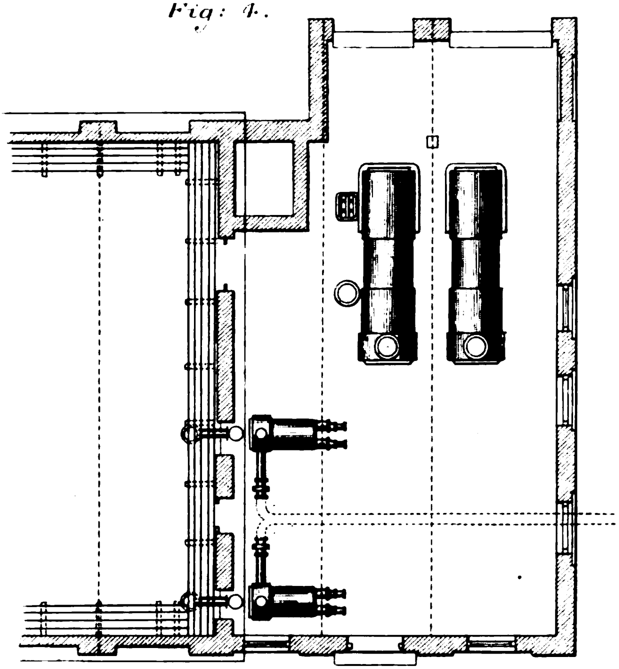

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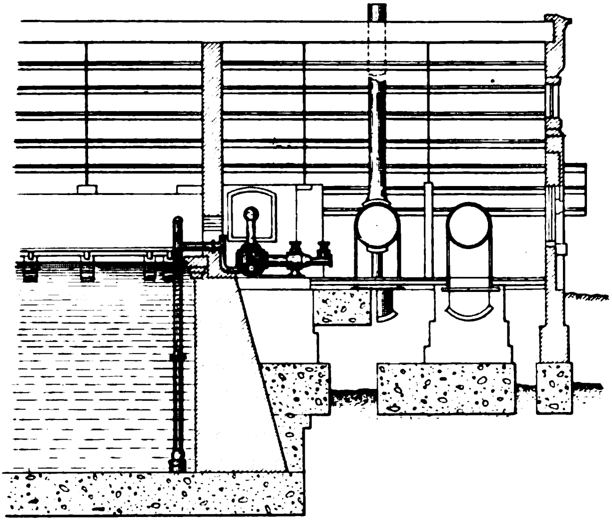

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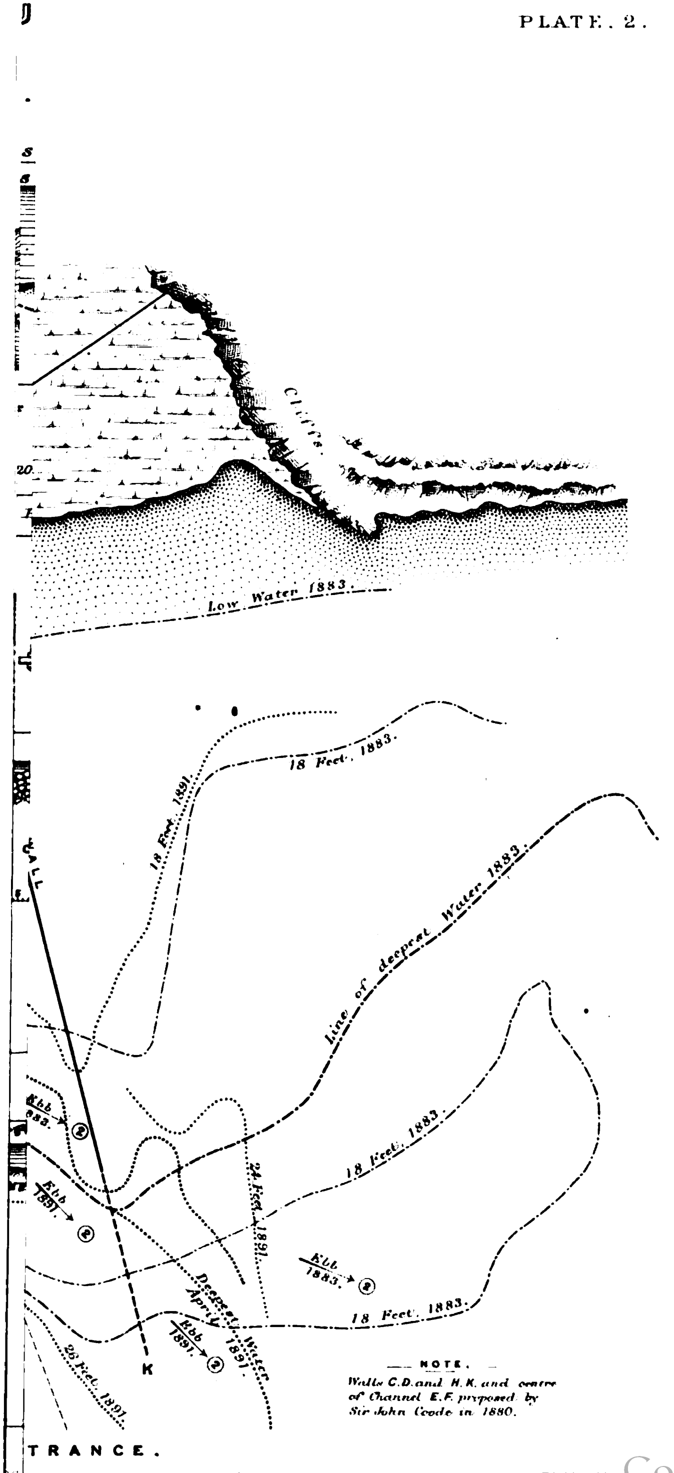
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THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

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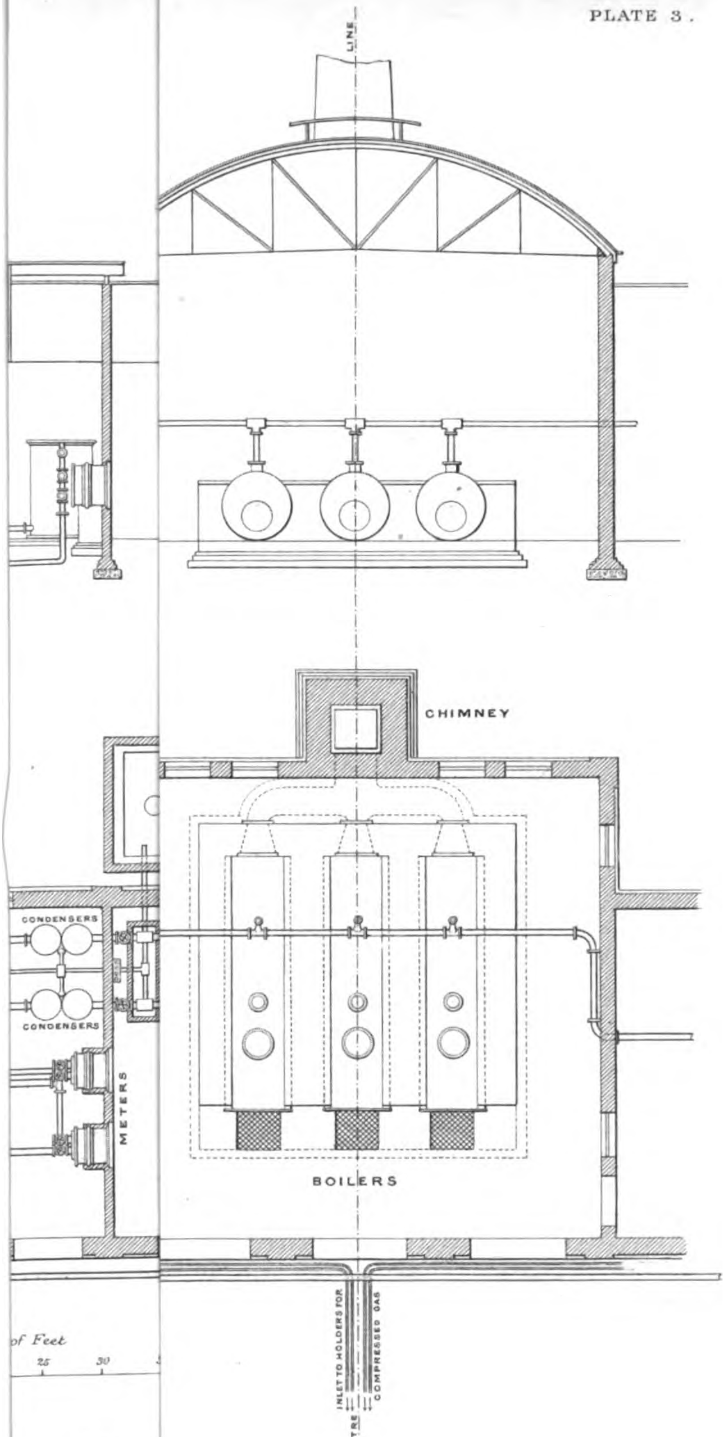
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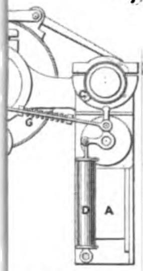

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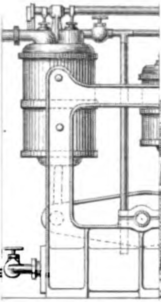

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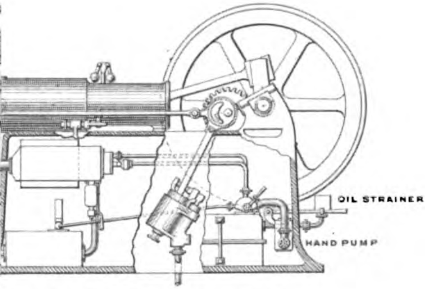
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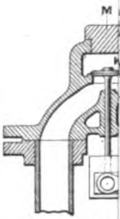

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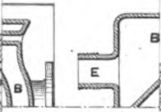

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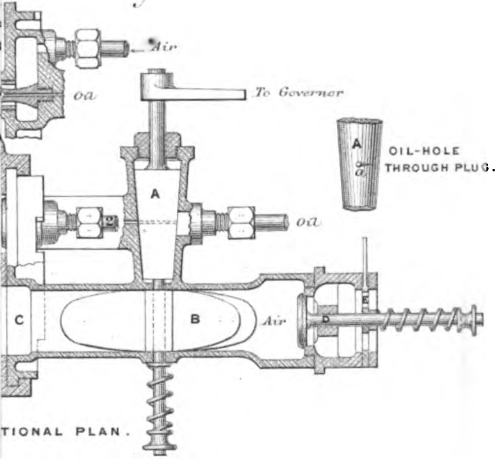
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GOVERNOR COCK & SPRAY-MAKER.

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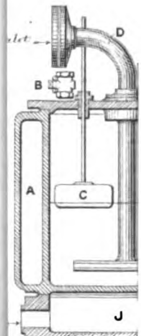

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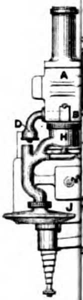

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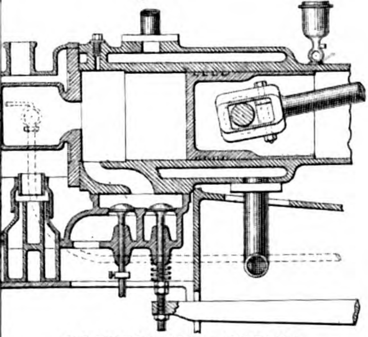

HORNSBY OIL-ENGINE.
SECTION THROUGH CYLINDER.

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